PAPERS AND PROCEEDINGS OF

THE ROYAL SOCIETY OF TASMANIA

Edited by M. R. Banks and M. J. Brown

and Published by the Society

Hobart

Tasmania

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PAPERS AND PROCEEDINGS OF THE ROYAL SOCIETY OF TASMANIA
VOLUME 134

Contents

page

Corrigenda — Volume 133, Part 1: Jackson, Ling; Volume 133, Part 2: Cover. iv

Refereed papers:

JACKSON, W.D. — Nutrient stocks in Tasmanian vegetation and approximate losses due to fire 1

HINGSTON, A.B. — Impacts of logging on autumn bird populations in the southern forests of Tasmania 19

PINDER, A.M. & ERSEUS, C. — New Phreodrilidae (Annelida: Clitellata) from Tasmanian estuaries 29

BRERETON, R.N. & TAYLOR, R.J. — Composition, seasonal occurrences and habitat use of bird assemblages in wet forests on the Central Plateau of Tasmania 35

WILLIAMS, K.J. & MARSDEN-SMEDLEY, J.B. — Reconnaissance survey of a glaucous eucalypt near Louisa Bay, southwestern Tasmania 45

JACKSON, J. — Threatened Trichoptera (caddisflies) from the Tasmanian Wilderness World Heritage Area 55

SUTER, P.J. — *Edmundsiops hickmani* sp. nov., *Offadens frater* (Tillyard) nov. comb. and description of the nymph of *Cloeon tasmaniae* Tillyard (Ephemeroptera: Baetidae) from Tasmania 63

GILMOUR, C.A., CROWDEN, R.K., VAILLANCOURT, R.E., & KOUTOULIS, A. — Genetic variation in the *Epacris tasmanica* complex (Epacridaceae) 75

SHEA, G.M. — The earliest taxonomic description and illustration of an Australian reptile: another historical first for bluetongue lizards (Squamata: Scincidae: *Tiliqua*) 79

HARRIS, S. & SUMMERS, S. — The desertification of a Bass Strait Island and a plan for its recovery: the case of East Kangaroo Island, Furneaux Group 83

Guide for authors 91

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TASMANIA

UNIVERSITY OF TASMANIA

PAPERS AND PROCEEDINGS OF THE ROYAL SOCIETY OF TASMANIA
VOLUME 133

Corrigenda

Part 1
Paper by **W.D. Jackson** on "The Tasmanian legacy of man and fire". The loss of some text within figure 1 on page 2, present in an early printer's proof, was not detected prior to printing. Herewith a correct version of the figure.

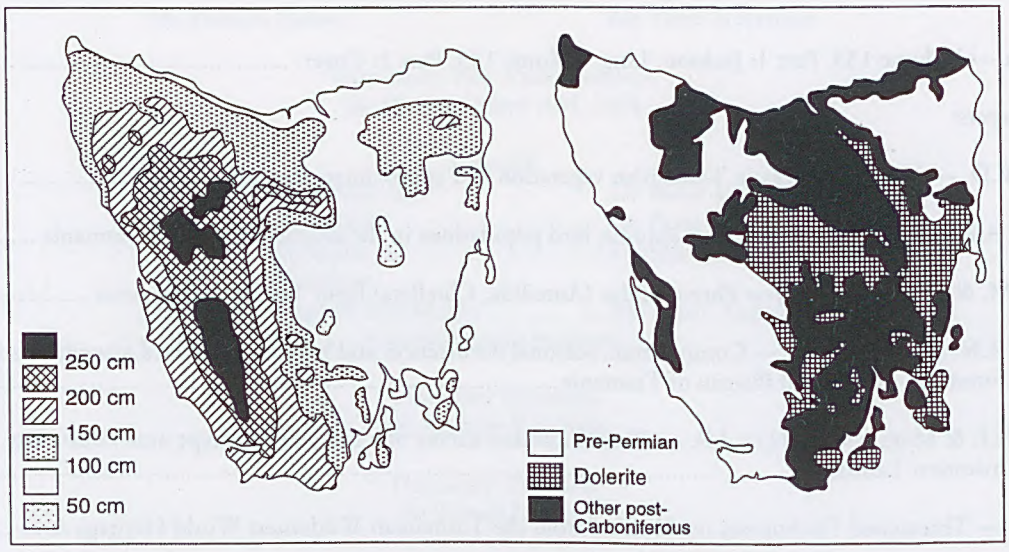


FIG. 1 — The general pattern of precipitation and geological exposure simplified from several sources.

Paper by **J.K. Ling** on "Elephant seal oil cargoes from King Island, Bass Strait, 1802–1918 with estimates of the numbers killed and size of the original population". On p.51, INTRODUCTION, line 4 should read "instructed Acting Lieutenant Murray of H.M. Brig *Lady Nelson* ..." **not** "instructed Lieutenant James Grant ...".

Part 2 — Heard Island
At the foot of p. iii, the Contents page, the front cover should have been shown as "taken by A.J. Graff" not "taken by A.J. Graft".

NUTRIENT STOCKS IN TASMANIAN VEGETATION AND APPROXIMATE LOSSES DUE TO FIRE

by W.D. Jackson

(with seven tables and two text-figures)

JACKSON, W.D., 2000 (31:xii): Nutrient stocks in Tasmanian vegetation and approximate losses due to fire. *Pap. Proc. R. Soc. Tasm.* 134: 1–18. ISSN 0080–4703. School of Plant Science, University of Tasmania, GPO Box 252-55, Hobart, Tasmania, Australia 7001.

Previously published data on the mass and concentration of major nutrients in Tasmanian vegetation types are presented in common units. The losses of nutrients in intensely hot wild-fires occurring once or twice a century are calculated and used to estimate losses in more frequent but less intense fires. Potential losses from consumed foliage and litter and from erosion and leaching of ash post-fire are estimated. Losses of phosphorus as a percentage of the mass of that element in the above-ground biomass and litter in rainforest or wet and dry eucalypt forest range from 75–85%; losses in scrub, heath and sedgeland range from 35–45%. Losses of 18% in potassium and 30% in calcium in sedgeland fires are particularly serious impediments to successional processes in western regions.

Data are provided on the input of nutrients into the precipitation and its attenuation with distance from the coast. In the absence of studies of nutrient balance in Tasmania, the available data from Victoria have been analysed to provide some information which is probably applicable to eastern Tasmania. In addition, the study provides the input–output concentration difference for a number of Tasmanian watersheds and a table showing the outflow concentrations from a selection of catchments displaying a range of geology, precipitation input (P) and evaporation (E). In Tasmania, the large differences in P/E ratios between western and eastern catchments has a major nutritional effect. The input of sodium in the Yolande catchment in the west is 1270 ppm, but the difference in input–output concentration is only 0.55 ppm, whereas the Lisdillon catchment in the east has a sodium input of 180 ppm, but a concentration difference of 20 ppm, indicating the effect of high evapotranspiration on the residence time and availability of nutrients. In precipitations of >2000 mm in western Tasmania, the large input of nutrients is balanced by equally large outflows from both rainforest and sedgeland. Thus, any additional mineralised nutrients following a fire will probably be lost by erosion, leaching or run-off. The data suggest that hot fire should not be used to regenerate cut-over forests in environments with high P/E ratios.

The relatively high predominance of disclimax fire-tolerant vegetation such as sedgeland and scrub in western Tasmania is due to the combination of a long period of Aboriginal burning during the Late Pleistocene and the low occurrence of clay-forming minerals in the geological exposures. In the eastern half, the topographical capping of dolerite has done much to supply an erosional mix of clay-forming minerals, so that the occupation of this region by Aborigines during the Holocene had a lower impact.

Key Words: nutrients, loss, fire, vegetation, Tasmania.

INTRODUCTION

The long period (~34 000 yrs) of occupation of Tasmania by humans has been well documented by Cosgrove (1995: fig. 16). Jackson (1999d) suggested that the period of occupation was likely to have been much longer, because of probable underestimation of age by the C^{14} dating methodology in Tasmanian conditions (Colhoun 1986). The palaeohistory of the vegetation derived from the Darwin impact crater indicates an anomalous change in the proportions of forest and open vegetation commencing approximately 70 000 years ago (Jackson 1999d).

The Aborigines used fire extensively, not merely for cooking and warmth but in communication, as a weapon, in hunting and, most importantly, as a management practice to increase herbivore production. The systematic patch-burning of vegetation to create "greenpick" grazing was extensively used. As a consequence of this widespread use, and of the fact that fire was transported from place to place by smouldering firesticks (Ling Roth 1899), many accidental wild-fires were started. Every summer it would be inevitable that fires were already burning when extreme fire-hazard weather occurred, leading to extensive, hot, intense wild-fires (Marsden-Smedley 1998). The limited occurrence of lightning-induced fires in Tasmania has been previously noted (Jackson & Bowman 1982, Ingles 1985, Jackson 1999d). Thus, the presence of humans using fire intensively would have caused a massive increase in the frequency of wild-fire due to accidental fires in extreme fire-hazard conditions (Jackson 1999d). Jackson advanced the argument, based on the results of an analysis of palaeovegetation history in the core of the Darwin Crater (Colhoun & van de Geer 1998), that the present large proportion of disclimax vegetation developed over the Last Glacial Cycle as a result of fire associated with the presence of man (Jackson 1999d).

In this recent article (1999d) Jackson revived an earlier thesis (Jackson 1968) that fire, vegetation and soil are closely related via a series of feedback relationships. It was proposed that recurrent fire regimes interrupt the reproductive cycles of plants, causing sudden changes in the distribution of plant communities, if the interval between consecutive fires is either too short or too long — the "ecological drift" theory (Jackson 1968, Noble & Slatyer 1981). Furthermore, recurrent fire encourages vegetation with lower nutrient requirements and greater reliance on vegetative reproduction or dependence on fire for regeneration. Fires cause a direct loss of nutrients by the removal of volatilised elements and particles in the updraft (Harwood & Jackson 1975, Bowman & Jackson 1981, Raison *et al.* 1985a, b, 1990, 1993, Walker *et al.* 1986, Fisher & Binkley 2000). Further losses of mineralised nutrients in the ash residue occur through gravitational movement due to wind and water and in solution both in run-off and down the soil profile by leaching (Bowman &

Jackson 1981, Bowman *et al.* 1986, Raison *et al.* 1993). Such losses relative to gains, from the input in precipitation and from the weathering of the geological parent materials, in time can reduce the availability of nutrients in the soil pool to the extent that vegetation types with a high nutrient demand become restricted. This present paper draws together the available data on nutrient limitation to vegetation in Tasmania and the impacts of fire on it.

FIRE AND NUTRIENT LOSS

Fire in natural vegetation is a major disruptive factor, changing the above-ground pools of organically complexed nutrients into a volatile or an inorganic mineralised state. Combustion accomplishes in a few minutes the process of nutrient transformation which would normally take five to ten years and, in some cases, much longer by biological decomposition. The loss of nutrient capital due to fire is difficult to estimate. Fire intensity affects nutrient transformations (Raison *et al.* 1993, Fisher & Binkley 2000). Hot, intense wild-fires, once they gain sufficient rate of spread, create fire-storm winds and strong convection updrafts which carry gases, burnt vegetation, ash and surface soil to high altitudes to be dispersed downwind, and, in Tasmania, often out to sea (McArthur 1968, Cheney 1981). The fire intensity (energy per metre of fire-front) is in the range 7000–70 000 kw/m and flame heights are >15 m (Cheney 1981, Fisher & Binkley 2000). All the canopy foliage is consumed in such fires along with the understorey and litter. Slow, cool fires consume the litter and foliage up to a few metres leaving most nutrients as residual ash, although about 80% of the volatile elements N and S are lost as gas with significant 40–60% non-particulate losses of P and K (Raison *et al.* 1985a, b). Fires which consume the forest duff or peat may burn slowly for long periods, causing massive mineralisation of the nutrient-rich pools of the surface organic soil. In such fires, some of the nutrients stay on the site as ash but are subject to erosion downslope and to leaching down the soil profile (Maclean 1979, Bowman & Jackson 1981, Bowman *et al.* 1986).

In most ecosystems, both soil and vegetation are the product of climate, geological influences and disturbances. In the absence of disturbance, the time required to achieve a climatic climax is controlled by geological characteristics such as the weathering rate and the mineral composition of the exposure. Palaeontological evidence from cores of the Darwin Crater in western Tasmania and from the Chatham Rise off the South Island of New Zealand shows that the vegetation has alternated between forest, largely rainforest, and open herbaceous communities with the cycles of glacial and interglacial climates during the Late Pleistocene (Jackson 1999d). The climax in these ecosystems has been established during each alternation in approximately 2500 years. In these insular temperate climates, the incidence of natural lightning-induced fire is low, and the input of nutrients in the precipitation is high and dependable. In western Tasmania previous to the last glacial cycle, the alternation of forest–herbaceous vegetation occurred on geological exposures of highly siliceous Cambrian and Precambrian sediments, which are very slow weathering and have minimal clay-forming minerals. The present extent of disclimax vegetation in this area appears to be the combination of fire disturbance due to presence of humans during the Last Glacial Cycle and the low inherent fertility of many of the geological exposures of the region. Although most regions of western Tasmania have suffered wild-fire at least once in the last two hundred years (Marsden-Smedley 1998), there are rare forests indicating very long periods of fire-free disturbance. In the Boyd River catchment, small patches of callidendrous rainforest occur on highly infertile Cambrian quartzwacke sediments where the P content of the parent material is undetectable (Harwood 1972, Jackson 1977). In such instances of low disturbance, the biomass gradually increases its nutrient capital by accumulation of cyclic salt input in the precipitation. Adequate N is fixed by the large mass of micro-organisms in the epiphytes in the Tasmanian rainforest canopy (Parker 1982).

Fire causes a loss of nutrients from the site due (Raison *et al.* 1993, Fisher & Binkley 2000) to

- volatilisation and particle loss in the updraught of the fire,
- wind transport of the ash,
- gravitational movement of the ash and charcoal downslope by run-off water,
- solution in the run-off water and
- leaching of dissolved ions down the soil profile.

Even slow, cool fires which consume little more than the litter layer cause transformation of significant nutrients from complexed biological states to gases or mineral forms that can be solubilised. If the surface organic soil is sufficiently dry at the time of intense fire incidence, it can also be consumed. Such peat or duff fires cause mobilisation of a large proportion of the total nutrient capital of the site, rendering it susceptible to potential leaching and erosion. As Ellis & Graley (1987) have pointed out, the current vegetation sometimes produces greater changes to soil fertility than the previous fire history. However, the effect of erosion following fire on slopes is a major contribution to soil loss, lower fertility and vegetation change.

VEGETATION AND FIRE

Short descriptions of the vegetation in Tasmania are available (Jackson 1965, 1981, 1999a) and detailed accounts of the important types are given in the *Vegetation of Tasmania* (Reid *et al.* 1999).

In other studies, the general environment (Jackson 1999b, d), the fire environment (1981, 1999b: 34–36) and the distribution of vegetation (1999a: figs 1.1, 1.3) have been covered. The areas estimated at 1800 and at present with the average fuel loads and fire-free intervals are shown in table 1. The following notes on the principal vegetation types supply a brief outline sufficient for an understanding of the influence of recurrent fire on these communities in the past and present.

Alpine and montane vegetation

Falling embers from hot wild-fires in lowland forests have probably always been a cause of spot-fires in montane regions. However, it is certain that the damage to montane vegetation has increased markedly since European settlement, due principally to the burning practices of graziers operating leaseholds of summer pasturage on the high country. One fire of this source in the summer of 1961–62 burnt nearly 128 000 ha (Mitchell 1962). Large proportions of the *Athrotaxis* forest and coniferous shrubberies were killed (Jackson 1973, Kirkpatrick & Dickinson 1984b, Kirkpatrick *et al.* 1995).

TABLE 1
Areas of vegetation types pre-1800 and at present, fire interval and fuel load

Vegetation type	% area pre-European*	% area present†	% area northwest‡	% area southwest§	Fire-free interval yrs	Combustible fuel t/ha¶
rainforest	9.8	8.5	26.2	19.5	150–300	25–30
swampforest	0.6	0.2	0.2	–	100–200	20–30
wet sclerophyll	19.2	14.6	24.9	15.7	80–150	180–320
dry sclerophyll	43.1	23.1	2.1	–	20–80	20–30
grassland	1.3	0.8	1.1	–	10–25	4–8
heathland	6.4	3.4	1	–	10–30	10–20
alpine	1.7	1.7	3.2	4	100–250	10–15
saltmarsh	0.06	0.05	–	–		–
wetland	0.4	0.2	–	–	40–80	2–4
sedgeland	17.4	17.2	27.4	56.2	20–40	10–30
total %	100	70	86.2	95.4		
cleared land %	–	30	13.8	4.6		
area millions ha	6.62	6.62	1.34	1.23		

* Proportionate area of each vegetation type estimated to exist pre European settlement (Kirkpatrick *et al.* 1995) relative to the whole state of Tasmania.
† Proportionate area (1995) relative to the whole state of Tasmania (Kirkpatrick *et al.* 1995).
‡ Proportionate area of the northwestern quarter (west of Forth River to Mt Manfred, estimate Kirkpatrick & Dickinson 1984a).
§ Proportionate area of southwestern quarter protected region (modified after Marsden-Smedley 1998) after allowances for roads and impoundments.
The average interval between consecutive fires (Jackson 1968).
¶ The average quantity of combustible fuel in tonnes per hectare at the time burnt, compiled from a number of sources.

Temperate rainforest

Fire is rare in rainforest because the closed canopy maintains moisture content well into drought conditions. Low amounts of litter, low flammability and sparse understorey limit invasion of ground fires. The largest threat is from spot-fire embers setting the dense epiphytic moss and lichen load in the canopy alight when humidities are very low.

Mixed forest

The age of mixed forest varies over a very wide span (Jackson 1999d; this paper, fig. 1A, table 1). Close to sources of fire from open vegetation, the tree ages are commonly 50–100 yrs, reflecting the occasional overrun of fire across the forest boundary (fig. 1A). In scattered patches within the sheet of rainforest, ages extend from about 200 to 300 years, the patches of eucalypt overstorey being maintained by chance spot fires often from upwind sources of sedgeland (fig. 1B, C). The eucalypts in forests approaching 300 years of age are overmature, with moribund crowns, and often have a density of less than five trees per hectare (fig. 1A, B). The presence of eucalypts with large litter-cones of bark and leaves increases the risk of spot-fires in mixed forest. This elevated mass of sclerophyllous litter is easily ignited by falling embers in times of drought.

Wet sclerophyll forest

Fires in wet sclerophyll forest are rare but very intense, usually killing all trees. Regeneration is from seed from fire-resistant capsules shed soon after crown-fire scorch. Dense stockings result from the large fall of two to four years of viable seed held in the crowns. The consequent thinning over the first 80 years of growth to reduce the stocking from many tens of thousands to about 80 stems per hectare (Gilbert 1959) plus the branch fall from remaining dominant trees contributes to the equilibrium fuel loads of up to 400 t/ha, with litter and duff component up to 160 t/ha (Frankcombe 1966, Wells & Hickey 1999). The updraught from the fire-storm of wild-fires in severe fire weather conditions causes a rain of embers downwind, creating spot-fires up to more than 50 km distant (Cheney 1981).

Dry sclerophyll forest

The fire-free interval is short, ranging from ten or less to about 50 years. There is a continued accumulation of litter fuel in the drier sites in Tasmania due to the slow decay of the sclerophyll litter and limited termite activity. The litter layer contains 50–75% of the consumable fuel mass, and fuel accumulation continues to >20 t/ha after 30 years on sites with <700 mm precipitation but plateaus around 15 t/ha on sites with >700 mm precipitation (Bresnehan 1998). It seems likely that, in dry *Eucalyptus amygdalina* forests with a heathy understorey, the steady state of litter accumulation would exceed 30 t/ha. The *Eucalyptus* dominants of the dry sclerophyll show a marked ability to recover vegetatively from even intense fires by the survival of dormant buds under the dead phloem of the main trunk and larger limbs (Jacobs 1955, Pryor 1976). This epicormic growth sustains carbon fixation till the crown dominance is again asserted. Very dry habitat species recover principally from similar buds in the massive lignotubers (Reid & Potts 1999).

Grassland/sedgeland

These communities appear to derive from the burning regimes of the Aborigines during the Holocene. They may be divided into two types:

(a) Open savannah merging into grassy, open dry sclerophyll forest in dry habitats usually <800 mm in low-land environments. At the time of European settlement,

they extended throughout the east and north in the Midlands Graben and in the valleys of the larger streams (Fensham 1989, Jackson 1999d). These sparsely forested areas were quickly usurped by European graziers. Sheep-grazing has removed the previously rich intertussock herb layer and prevented the establishment of forest except at the margins, where advancing pole stands of eucalypts demonstrate the probable nature of the vegetation in the absence of disturbance (Duncan 1990). Where a short interval free of fire is maintained, the shrub storey of dry Eucalypt forest is slowly converted to a grassy sedgy understorey.

(b) *Poa billardieri* tussock grassland and grassy open *E. delegatensis* forest with corridors of forest on streams. These occur on moderately fertile soils on parent materials of basalt, granite or limestone on plateaus in the north at altitudes of 600–1100 m. These grasslands in the northeast and northwest have been rapidly invaded by forest since European settlement by the succession of *Leptospermum–Eucalyptus–Nothofagus*. The eucalypt forest has a short tenure, due to die-back associated with rainforest invasion (Jackson 1981, Ellis 1986).

Heathland

Due to the intense utilisation of the coastal regions by the Aborigines in the Holocene, heathy communities have been extended inland by fire at the expense of the dry sclerophyll forest. Within the broad region dominated by dry sclerophyll forest there are many small patches of heath on sites where the watertable is high enough to create edaphic limits to trees. These sites are common on duplex soils of Permian and Triassic sediments. It is likely that most heathland was patch-burnt by the Aborigines every ten to 15 years to prevent closure by shrubs and to generate "greenpick" grazing conditions (Kirkpatrick & Harris 1999).

Sedgeland/heath or blanket moor

The blanket moor carries sedges and an open shrub element of Epacridaceae, Myrtaceae and Proteaceae (Brown 1999). The moorland will carry fire even in damp conditions and burns intensely in drought. Where the fire-carry or intensity is limited by creeks or polar slopes, a dense wet scrub community of *Leptospermum*, *Agastachys* and *Bauera* develops until it is consumed by a hot fire. In valleys the peat depth may reach over 1 m but on steep slopes may be no more than a few centimetres. Most fires consume only the above-ground vegetation. From such fires *Gymnoschoenus* recovers quickly because of the large energy reserves held in the rhizomes. However, after prolonged drought, fires may consume the peat with serious losses of nutrients due to mobilisation and solution (Bowman & Jackson 1981, Jackson 1999d).

TASMANIAN DATA ON NUTRIENT LOSSES AND INPUTS

Losses due to Wild-fire and Estimation of Consumable Biomass

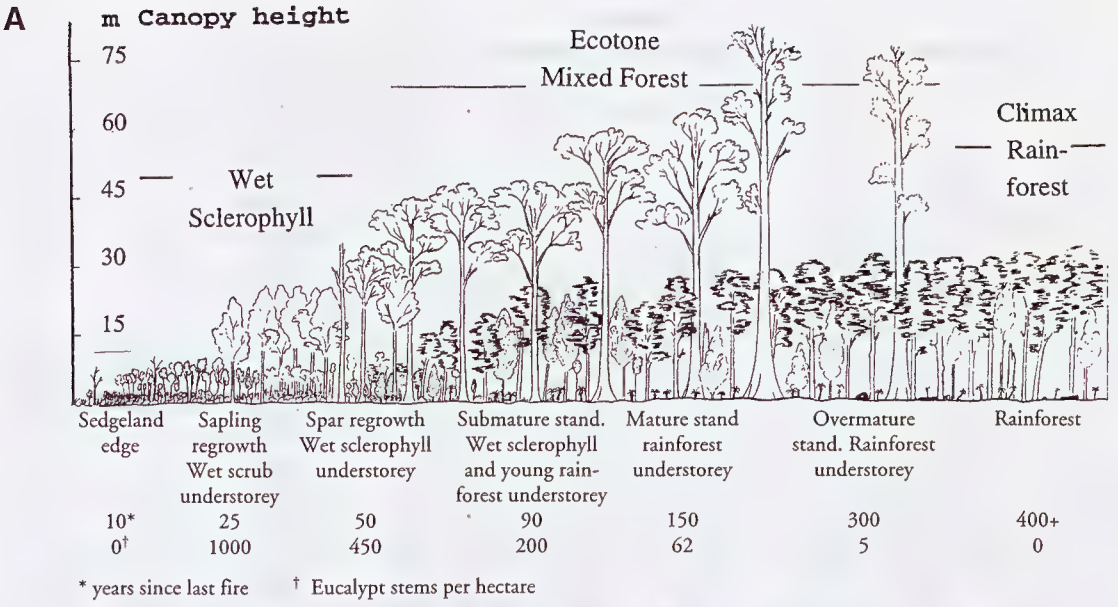
An attempt has been made in table 5 (see later) to collect the available data on potential nutrient loss due to very intense wild-fire in typical examples of vegetation types in Tasmania. This will hopefully provide a nutritional basis for the discussion on the patterns of vegetation discussed by Jackson & Brown (1999). The basis for the data in table 5 is provided by the estimated consumable masses shown in table 2, which have been collected from a number of published sources. These sources vary in sampling techniques, methods and analysis; hence, the original sources should be consulted to obtain their relative reliability. However, variability in the accuracy of the source data is small compared with the large potential errors in estimating fire-intensity effects when applying the estimates in table 5 to fires of lower intensity.

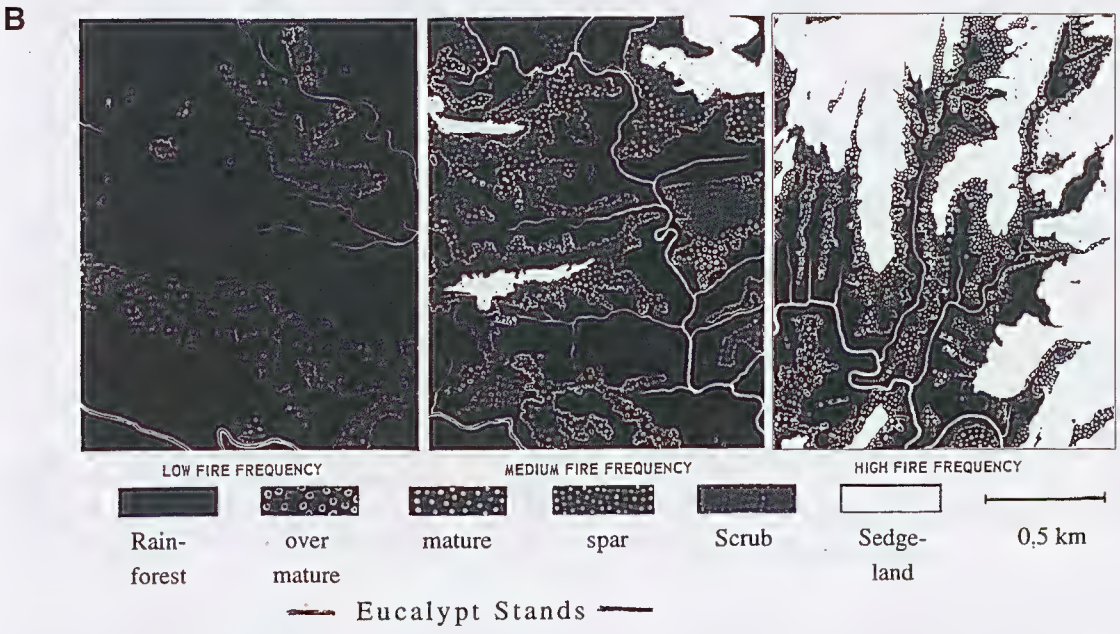
Where possible the concentration of elements is expressed in kg/ha, otherwise in ppm. Elements are denoted by their chemical symbols. Concentrations of the important elements N and P are variously assessed in the form of ammonium ($NH4^+$) and available P. Where measured, the available form is used in all tables.

It must be stressed that the losses shown in table 5 are based on the losses incurred in the extremely intense wild-fires occurring once or twice a century in Tasmania (Marsden-Smedley 1998). Evidence gained from the inspection of sites which had carried wet sclerophyll forests, dry sclerophyll forests, shrubland and grassland before the 1967 fire in southeastern Tasmania was that complete removal of ash and considerable surface soil was general on all sites, due to the strong updraft.

The losses in these very intense wild-fires are used in table 5 because they allow a complete inventory of losses of nutrients from the fire site. Losses of nutrients in less intense fires are much lower and are highly variable, due to the range of fuel consumed and the range of fire-intensity effects on volatile and particle loss in the smoke, transportation of elements into various mineral states in the ash, consumption of duff, removal of soil in the updraft, heating of the soil, exposure to erosion and leaching (Raison *et al.* 1993, Fisher & Binkley 2000). Estimates of losses via atmospheric transfer in burning logging slash in forest regeneration in the Florentine Valley were approximately 15–20% in P, K, Ca and Mg (Harwood & Jackson 1975). Losses of nutrients in smoke during cool fuel-reduction fires are expected to be only 1–5% of the losses suggested in table 5. However, Raison *et al.* (1985a, b) have established relationships between the percentage of fuel mass consumed

FIG. 1 (opposite) — (A) Forest structures in environments with precipitation >1950 mm per annum as determined by age since the last fire. (B) Vegetation patterns associated with various fire frequencies showing the progressive replacement of rainforest on ridge crest by mixed forest, eucalypt forest, scrub, heath and sedgeland with increasing fire frequency. Pieman River region, Tasmanian west coast; rainfall 2250 mm/annum. (C) Probability distribution of occurrences of eucalypt stands in rainforest with distance from isolated areas of sedgeland, the assumed sources of fire: (i) measured in a southeasterly direction, i.e. down prevailing wind as the most likely direction of spot-fire production; this direction is also transverse to the dissection pattern and the major geological axis of folding; (ii) measured from the nearest fire source irrespective of direction. The probability distribution illustrates the effect of spot-fires on successive ridges due to embers. Source of data: analysis of 56 500 ha of rainforest in the Mt Bertha area; rainfall 2250 mm.


A
m Canopy height
75
60
45
30
15
Ecotone
Mixed Forest
Wet
Sclerophyll
Climax
Rain-
forest
Sedgeland edge
Sapling regrowth Wet scrub understorey
Spar regrowth Wet sclerophyll understorey
Submature stand. Wet sclerophyll and young rain-forest understorey
Mature stand rainforest understorey
Overmature stand. Rainforest understorey
Rainforest
10*
25
50
90
150
300
400+
0†
1000
450
200
62
5
0
* years since last fire
† Eucalypt stems per hectare


B
LOW FIRE FREQUENCY
MEDIUM FIRE FREQUENCY
HIGH FIRE FREQUENCY
Rain-forest
over mature
mature
spar
Scrub
Sedge-land
0.5 km
Eucalypt Stands

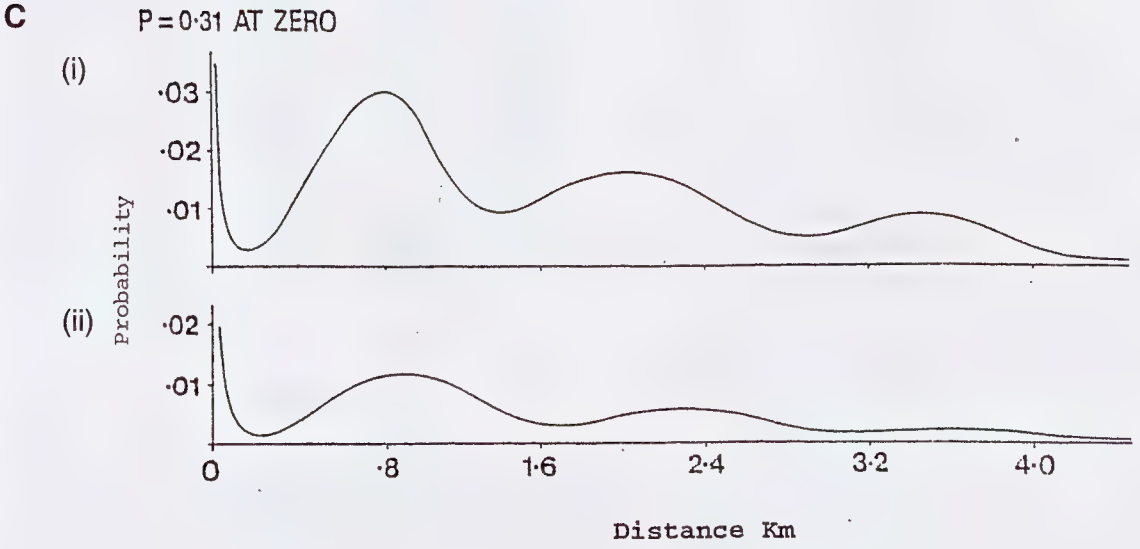

C
P = 0·31 AT ZERO
(i)
·03
·02
·01
Probability
(ii)
·02
·01
0
·8
1·6
2·4
3·2
4·0
Distance Km

TABLE 2
Sample potential masses of nutrients consumed in intense wild-fires

vegetation	component*	mass (t/ha)	elemental concentration (kg/ha)				
			N	P	K	Ca	Mg
callidendrous	foliage	11.4	123.7	12.9	95.1	36.6	11.5
rainforest	litter-fall	4.34	27.1	2.1	11.6	18.2	2.3
aged >400 yrs	o.g. biomass	493	597	66	603	460	62
Saddleback, NE Tas.							
1600 mm	cons. o.g. mass	10.57	82.3	10.05	67.7	43.2	9.36
Jurassic dolerite	litter	14.3	102.9	7.85	8.58	119.4	15.3
(Adams & Attiwill 1988)	tot. consumable	24.87	185.2	17.9	76.3	162.6	24.66
	eq. yrs litter-fall	5.7	6.8	8.5	6.6	8.9	10.7
Eucalyptus regnans	foliage	10.9	114.6	6.7	61.1	39.7	20.4
wet sclerophyll	litter fall	5.34	32.1	1.4	9.5	25.1	5.2
aged 80–100 yrs	o.g. biomass	472	698	39.9	419	811.9	123.2
Retreat, NE Tas.1000 mm	cons. o.g. mass	154.6	329.6	10.98	149.9	110.7	37.3
Mathinna quartzwacke	litter	24.5	174	6.85	39.2	136.3	19.8
(Adams & Attiwill 1988)	tot. consumable	179.1	427.2	17.83	189.1	247	57.1
	eq. yrs litter-fall	33.5	13.3	12.73	19.91	9.84	10.98
E. obliqua	foliage	6.6	80.2	4.3	25.6	27.2	15.4
dry sclerophyll	litter fall	4.31	19.51	1.01	4.2	19.7	4.8
aged 100 yrs	o.g. biomass	363	430	19.2	238	306	62.1
Emu Ground, NE Tas.							
800 mm	cons. o.g. mass	11	93.4	5.36	43.86	56.98	22.28
Mathinna quartzwacke	litter	20	82.3	2.78	8.08	71.7	10.2
(Adams & Attiwill 1988)	tot. consumable	31	175.7	8.14	51.94	128.59	32.48
	eq. yrs litter-fall	7.2	20.92	27.13	30.55	14.29	21.65
E. amygdalina	foliage	7.6	98.9	5.2	36.3	28.8	12.4
dry sclerophyll	litter-fall	1.95	8.4	0.3	1.7	9	1.5
aged 100 yrs	o.g. biomass	158	281	12.1	145	346	46.7
Turquoise Bluff, NE Tas.							
750 mm	cons. o.g. mass	11.2	105.3	5.7	42.6	64.8	16.4
Mathinna mudstone	litter	10.3	53.5	1.33	4.47	64.5	7.18
(Adams & Attiwill 1988)	tot. consumable	21.5	158.8	7.03	47.07	129.3	23.58
	eq.yrs litter-fall	11	18.9	23.4	27.7	14.4	15.7
E. nitida–Leptospermum nitidum	foliage	6.4	–	3.18	38.9	40.5	14.7
wet scrub	litter-fall	2.06	12.03	0.53	3.56	9.41	1.95
aged 38 yrs	o.g. biomass	180	233	13.2	140	271	41
Hastings, S Tas. 1400 mm	cons. o.g. mass	57.9	123.5	3.68	55.5	41	45.5
Cambrian greywacke	litter	9.17	65.3	2.57	14.7	51.1	7.6
(Turnbull & Madden 1983)	tot. consumable	67.1	188.5	6.6	70.2	92.1	53.1
	eq. yrs litter-fall	10.5	15.7	33.4	48.2	37.7	27.2
Gymnoschoenus	live foliage	7	–	0.067	4.06	1.74	1.1
sedgeland	dead foliage/yr†	0.01	–	0.004	0.24	1.34	0.45
aged 7–30 yrs	dead fol/30yrs†	3	–	0.12	7.29	40.2	13.5
Condominium Ck–Orange							
R., SW Tas. 2000 mm	o.g. biomass	10	–	0.187	11.35	41.5	14.6
Precambrian quartzite	cons. o.g. mass	10	–	0.187	11.35	41.5	14.6
(Bowman *et al.* 1986)	litter	0	–	0	0	0	0
	tot. consumable	10	–	0.187	11.4	41.5	14.6
	eq. an. fol. death	3.3	–	46.8	47.5	31	32.4

* o.g. = above ground, cons. = consumable, eq. yrs = equivalent number of years of input from litter-fall.
† Dead foliage remains on *Gymnoschoenus*, the accumulated fuel is a major component of nutrient loss even though the retrievals of P and K at senescence are both 94%. (See footnote to table 3.)

TABLE 3
Foliar concentrations of major vegetation types in ppm of oven dry weight

Vegetation	Dominant or important species	Nutrients* P	K	Ca	Mg	Site	Ref.†
rainforest	*Atherosperma moschatum*	1740	12980	5810	1290	Saddleback, NE Tas	AA
		890	13100	6990	725	Boyd R., SW Tas	J
		[23]	[52]	[58]	[–30]		
"	*Nothofagus cunninghamii*	1540	6500	2200	480	Saddleback, NE Tas	AA
		740	5450	6990	720	Boyd R., SW Tas	J
		[32]	[52]	[56]	[–23]		
gully forest	*Olearia argophylla*	1540	17800	5300	1830	Wallaby Ck, SE Vic	A
wet sclerophyll	*Eucalyptus regnans*	780	5730	5730	3170	Wallaby Ck, SE Vic	A
"	*Pomaderris aspera*	1800	11310	14234	3230	Wallaby Ck, SE Vic	A
"	*E. obliqua*	730	6660	4320	2210	Retreat, NE Tas	AA
dry sclerophyll	*E. obliqua*	650	3400	4140	2350	Emu Ground, NE Tas	AA
"	*E. amygdalina*	700	4820	3820	1640	Turquoise Bluff, NE Tas	AA
grassland	*Festuca*	590	3280	3700	1400	Devonshire Dales, Engl.	Ll
wet sclerophyll	*E. nitida*	374	2880	3890	1530	Boyd R., SW Tas	J
		[27]	[60]	[–14]	[5]		
woodland/scrub		318	3890	4050	1470	Condominium Ck, SW T	M
wet scrub	*Leptospermum nitidum*	207	3430	3550	1480	Condominium Ck, SW T	M
dry heath		175	3300	5300	2150	Dark Island Hth, SA	S
wet heath	*Melaleuca squarrosa*	122	2940	8640	2020	Condominium Ck, SW T	M
"	*Sprengelia incarnata*	100	2450	4320	670	Condominium Ck, SW T	M
sedgeland	*Lepidosperma filiforme*	113	4090	540	950	Orange River, SW Tas	M
		[93]	[93]	[18]	[18]		
"	*Gymnoschoenus sphaerocephalus*	67	4060	1100	1740	Orange River, SW Tas	M
		[94]	[94]	[23]	[59]		
"	*Leptocarpus tenax*	10	3300	900	410	Orange River, SW Tas	M

* Figures in square brackets are the withdrawal percentage of the nutrient upon leaf senescence before leaf-fall; negative figures indicate excretion during senescence.
† References: AA – Adams, M.A. & Attiwill, P.M. (1988); A – Ashton, D.H. (1975); J – Jackson, W.D. (1977); Ll – Lloyd, P.S. (1971); M – Mclean, A.R. (1979); S – Specht, R.L. (1969).

and the percentage loss of elements to the atmosphere. This demonstrates that up to 40% of the P content of combusted fuel can be lost in some low-intensity fires. Erosion of the ash remaining after lower intensity fires is potentially a far greater cause of nutrient loss than either atmospheric or leaching losses (Raison *et al.* 1985a, 1993). Both erosion and leaching are likely to be important causes of nutrient loss following fire in the dissected high rainfall regions of western Tasmania. The application of the losses estimated in table 5 to fires other than very intense wildfires occurring once or twice a century in Tasmanian vegetation can only be made with due adjustment for the lower fire intensity.

Biomass

The nutrient status of important Tasmanian plant communities is indicated in table 3 by the foliar concentration of elements in community dominants in approximate order of P concentration. The distribution of these communities (Kirkpatrick & Dickinson 1984a, Jackson 1999a) demonstrates the limitations imposed by nutrient availability due to both the prevalence of highly infertile siliceous sediments (Seymour & Calver 1995) and the fire regimes associated with each vegetation type over a long period of human occupation (table 1).

Except where production is limited by water availability, biomass can reflect lack of disturbance due to the accumulation of nutrient capital in the vegetation and organic soil from the input of cyclic salt. The above-ground biomass in forests is also a function of age, due to wood accumulation. However, while there is a good relationship between foliage mass and the basal area of sapwood, the basal area of accumulated heartwood contributes little to the nutrient mass. This is particularly so in eucalypts, where there is a large transfer of nutrients from the heartwood as it matures (Attiwill 1980). In Tasmania, the total above-ground biomass is often a response to the time since fire and the water availability at the site. In dry sclerophyll forest, fire in the litter and understorey occurs at intervals usually of less than 50 years, but the trees are not killed by even intense fires. In wet sclerophyll and mixed forest, the long fire-free interval and the open canopy of the eucalypts allow the development of large quantities of fuel in the understorey and litter. The consumption of this by fire

kills most trees. Consequently, the consumable biomass of rainforest and other older mixed forest is lower than that of wet sclerophyll forest.

Nutrient Pools and Fluxes

The nutrient content of the litter layer and the surface layers of organic soil are probably more important reservoirs of nutrient capital in Tasmanian environments that in most mainland Australian habitats. This proposal is based on the lower decomposition rates of litter, the preponderances of shallow soil, lack of clay-forming minerals and the slow weathering rates and infertility of geological exposures in many Tasmanian habitats. Most feeding roots of vegetation including those of large forest trees exploit mainly the upper few centimetres of the soil profile especially in the infertile soils of western Tasmania. Nutrients in the soil are highly conserved as organic complexes in the micro-organisms. The supply of labile nutrients to the plants via the root system is largely dependent on the flux of nutrients in the litter-fall. The number of years litter-fall equivalent to the loss of nutrients by intense wild-fire is shown in table 5 as a representative measure of nutrient loss.

The pool of micro-organisms in the surface layers of the soil forms an important buffer against losses of nutrients by leaching of the ashes following a fire. The micro-organisms are able to grow rapidly by utilising the flux of nutrient ions dissolved from the ash thus immobilising otherwise labile nutrients. The role of soil micro-organisms in providing immobilisation after a fire is particularly important in forest soils (Vitousek & Matson 1984, Polglase *et al.* 1986). For this reason, the consequences of duff and peat fires are particularly detrimental to the regeneration of the vegetation. This is demonstrated by the replacement of rainforest by sedgeland species such as *Gahnia, Lepidosperma* and *Gymnoschoenus* following duff fires in poor soils (Hill & Read 1984, Barker 1991).

Litter Accession and Decomposition

The standing crop of litter is more variable than the litter-fall would indicate, due to the range in decomposition rates. Turnbull & Madden (1983) analysed the litter balance in southern Tasmanian wet forests near Hastings, where precipitation is ~1400 mm/yr. These results for litter-fall and standing crop are shown in table 4 and are similar to those of Adams & Attiwill (1988) for similar communities at Retreat and Saddleback shown in table 2. Turnbull & Madden (1983) developed a relationship between litter-fall and basal area (r^2=0.92), where the litter accession in kg/ha was 35.7x (basal area m/ha). This relationship has been used in table 2 to estimate missing data.

Decomposition constants (k) for dry sclerophyll forests in Tasmania are much lower than for wet forests. Although the accession rates are reduced, due to water limitation to production, the much slower decay of litter, due in part to the low activity of termites in Tasmania, more than compensates. Under the high average values of radiation inputs in eastern Tasmania (272–314 K joules/cm^2/yr [Nunez 1978], effectively doubled on steep northerly facing slopes [Holland & Steyn 1975]), the productivity is predominantly influenced by water availability rather than temperature. Dry sclerophyll in Tasmania is so regularly disturbed by fire that it is difficult to estimate what the steady state of litter might be. In a study of litter accession following fuel-reduction fires on sites in southeastern Tasmania, Bresneham (1998) found the k value for sites with precipitation >700 mm/yr was 0.135 whereas the k for sites with precipitation <600 mm/yr was 0.0005, giving an unrealistically high steady state of litter. Accession curves developed by Raison *et al.* (1983) for dry sclerophyll in the Blue Mountains of NSW suggest that steady states of litter (Xss table 4) in dry sclerophyll in dry regions of Tasmania are about 25–30 t/ha. Such accumulations on dry sites are rare because of fire. It should be pointed out that the *E. amygdalina* dry sclerophyll on the Turquoise Bluff site (table 5) was burnt two years before the assessment by Adams & Attiwill (1988) with a fire sufficiently hot to produce a strong crop of epicormic foliage.

Nutrient Loss Relative to Total Pools

Losses considered relative to the total pools are shown in table 5 where the input in the rainfall is shown in the first row, the consumable mass from table 2 in the second and the exchangeable mass in the upper 5 cm of the soil pool in the third row. The percentage loss in the above ground pools of foliage and litter relative to the total pools is shown in the last row for each vegetation type. The total pools in the soil are of course much greater than the available pools and the impact of losses in the long term may be in part addressed by the slow conversion of elements from their unavailable pools. However, the losses in intense wild-fire should be assessed against the exchangeable pools as these will determine availability during the regeneration phases. In less intense fires where ash remains, fire mobilises nutrients especially N and P, stimulating growth of the regeneration. The pool in the top 5 cm of soil has been used rather than deeper profiles because it has a far greater influence over the early phases of regeneration. Nutrient concentrations in the top 5 cm are about 4–7 fold greater than those in the next 15 cm of the soil profile. It has been demonstrated that draw-down on the supply of nutrients in the soil pool decreases after canopy closure, due to the flux of available cations resulting from competitive thinning of the vegetation. Litter-fall produces the majority of supply for Ca and Mg and also N, while through-fall supplies most of the K. P is predominantly cycled internally in the foliage and as the forest matures from the heartwood (Baker & Attiwill 1985, Attiwill *et al.* 1996).

Post-fire Erosion and Leaching Losses

Residual ash left by cooler fires is subject to erosion and leaching, moving the nutrient content downslope. This movement is considerable in Tasmania, due to the steep slopes of the topography. The first rains after a fire move considerable quantities of ash downslope in the surface run off. Further nutrients are removed in solution. However, quantitative data are difficult to obtain. It is probable that the flotation of charcoal fines over long periods accounts for significant nutrient loss adsorbed from the ash. The evidence of long-term gravitational movement of nutrients is abundant in Western Tasmania, where sedgeland heaths and scrub replace forests on ridge tops where spot fires are more frequent (fig. 1B, C).

The leaching of nutrients from residual ash is limited on

TABLE 4
Litter decomposition in southern forests*

Age	Basal area in m^2/ha				Litter-fall t/ha	Litter t/ha	k	t 0.5	Xss 95%	Xss 99%
63	*E. obliqua*	57.7+	various	39.2	5.31	22.15	0.240	2.89	12.5	20.8
>400	*E. obliqua*	3.2 +	*N.cunnh'ii*	79.6	4.69	11.93	0.393	1.84	8.0	13.2

If the decomposition constant k is defined as k=L/X, where L is the litter fall (t/ha) and where X is the litter mass (t/ha), dx/dt = L–kX then Xt the litter mass at time t (yrs) = $L/k(1-e^{-kt}) - X0\ (e^{-kt})$. When X0 the initial litter mass = 0, Xt the litter mass at time t (yrs) = $Xss\ (1-e^{-kt})$ where Xss is the steady state (yrs) and t0.5 the half life = 0.693/k , t95%ss = 3/k, t99%ss = 5/k (Olsen 1963).
* Turnbull & Madden 1983.

TABLE 5
Nutrient input and potential loss due to intense wild-fire percentage total pools including the top 5 cm of soil

Vegetation type	Available nutrient source	Elemental concentration kg/ha and % consumable N	P	Na	K	Ca	Mg
rainforest	ann. precip'n input	8.16	0.16	12.77	10.7	12.47	2.75
Saddleback	consumable	185.2	17.9		76.3	162.6	24.7
1662 mm*, 500 yrs†	soil pool	57.3	5.7	109.8	586.5	668	136
(Adams & Attiwill 1988)	cons/tot pool %	76	76		11.5	19.6	15.4
wet sclerophyll	ann. precip'n input	5.28	0.13	19.25	6.92	16.78	3.33
Retreat	consumable	427.2	17.83		189.1	247	57.1
945 mm, 120 yrs	soil pool	445	2.5	278.23	410.6	1243	533.9
(Adams & Attiwill 1988)	cons/tot pool %	49	88		31.5	16.6	9.7
dry sclerophyll	ann. precip'n input	3.92	0.1	22.41	4.49	13.25	3.19
Emu Ground	consumable	175.7	8.14		51.9	128.6	32.5
785 mm, 40 yrs	soil pool	145	2.2	242.7	559.1	315	213.8
(Adams & Attiwill 1988)	cons/tot pool %	55	79		8.5	29	13.2
dry sclerophyll	ann. precip'n input	3.66	0.1	20.8	3.03	13.46	3.13
Turquoise Bluff	consumable	158.8	7.03		47.1	129.3	23.6
773 mm, 15yrs	soil pool	180	1.3	222.1	459.4	488	285
(Adams & Attiwill 1988)	cons/tot pool %	47	84		9.3	20.9	7.6
wet sclerophyll/scrub	ann. precip'n input	–4.2	–0.15	–35	–1.4	–1.7	–4.2
Hastings	consumable	–189.	–7	–26	–70	–92	–53
1400 mm, 30yrs	soil pool		–1.7	–180	–210	–290	–315
(Turnbull & Madden 1983)	cons/tot pool %		–80	–13	–25	–24	–14
wet scrub	ann. precip'n input		–0.3	–59	–10	–16	–12
Olga River	consumable		1.56	16.08	31.36	18.04	66.04
2500 mm, 25 yrs	soil pool		2.1	160	262	276	574
(Maclean 1979)	cons/tot pool %		43	9.1	10.7	6.5	10.3
wet heath	ann. precip'n input		–0.14	–45	–8	–13	–10
Condominium Ck	consumable		1.03	9.27	25	47.5	8.1
2000 mm, 25yrs	soil pool		1.32	105	199	306	226
(Maclean 1979)	cons/tot pool %		44	8.1	11.2	13.4	3.5
sedgeland	ann. precip'n input		–0.3	–59	–10	–16	–12
Olga River	consumable		0.187	–	11.4	41.5	14.6
2500 mm, 25yrs	soil pool		1.19	–	53	101	117
(Maclean 1979)	cons/tot pool %		14	–	17.7	29	11.1

* Annual rainfall † Age of forest.

forest sites, due to the uptake of nutrients by the regeneration, the high cation-exchange capacity of the surface organic soil and the ability of the extensive microbial pool to expand and immobilise the mineralised nutrients (Vitousek & Matson 1974, Polglase *et al.* 1986, Adams & Attiwill 1988, Attiwill *et al.* 1996).

The flux of anions, especially bicarbonate, in the leaching water increases the loss of cations initially (Khanna & Raison 1986). However, in most forest soils, uptake by regenerating vegetation and immobilisation by the microbial pool usually prevent extended leaching, although this is very site-dependent. The analysis of soil water following fire suggests a return to close to prefire levels of nutrients after 18 months (Adams & Attiwill 1988). Where the surface organic-rich layers are burnt and are subject to severe leaching, the presence of significant clay in the soil profile probably limits extensive leaching losses. Large quantities of nutrients may be captured on the clay. Deep sandy soils without clay horizons are certainly strongly leached after fire. The muck peat soil formed by *Gymnoschoenus* sedgeland in Tasmania is acid (pH ~4) and anaerobic. It has exceptionally low nutrient content, due to the high withdrawal of nutrients at leaf senescence and the retention of dead foliage by the plant (table 3). As a consequence the loss of potassium in a fire is considerably greater than the content of the soil pool (table 5). Should the peat dry sufficiently to burn, serious erosion and leaching occurs (Maclean 1979, Bowman & Jackson 1981, Bowman *et al.* 1986).

Geological Influences

There are very large differences in the soil–vegetation pools of nutrients on the different geological exposures in Tasmania. However, the more fertile igneous exposures are limited in distribution (Seymour & Calver 1995).

The input from weathering of geological substrates can only be estimated. An estimate has been made by Attiwill & Leeper (1987) for weathering inputs for granite soils of high productivity in Victoria. The estimate is possibly applicable to some igneous exposures in eastern Tasmania. However, the lower subsoil temperatures in Tasmania are likely to cause slower weathering rates. Fast-weathering igneous rocks like basalt yield deep clay-loams or kraznozem soils which, in Tasmania, have been largely utilised for agriculture. The much slower weathering exposures of dolerite provide shallow clay-rich loams. These clay-rich soils resist nutrient depletion by erosion and leaching in typical recurrent fire regimes.

The weathering inputs on Permian and Triassic and Devonian sediments are about an order of magnitude lower than those of the igneous rocks, while those of the pre-Carboniferous sediments of western Tasmania are about two orders of magnitude lower. These highly siliceous, slow-weathering sediments are deficient in clay-forming minerals. The soils on these sediments are shallow, with acid organic surface horizons over leached sandy A1 horizons; they are susceptible to erosion and leaching following fire in the vegetation. Further, the organic soils are likely to be consumed in peat and duff fires, causing serious nutrient loss by erosion. Soil permeability and slope are major factors affecting erosion potential. Erosion is a key driver of soil and vegetation change.

The present maps of geological exposure (Seymour & Calver 1995) do not account for all of the soil–vegetation responses, because erosion has removed the thin cover of igneous rocks which was once more widely distributed in the west. The clay-forming minerals from these past covers are now incorporated in many soils. Additionally, large volumes of dolerite are perched at elevations >1000 m on mountain tops and on the Central Plateau on the western margin of the post-Carboniferous cover. During the Pleistocene, extensive ice-sheets and glaciers have deposited glacial till from the dolerite over wide areas of the pre-Carboniferous pavement to the west (Colhoun 1985, Kiernan 1989, 1990, Kiernan & Hannan 1991, Fitzsimons & Colhoun 1991, Jackson 1999c). The remains of these rocks have been widely distributed by the erosional forces and contribute clay-forming minerals to the soil, increasing its cation-exchange capacity. These relatively small additions of clay minerals do much to protect the soils on the otherwise highly quartzose sediments in the west from loss of nutrients from leaching after fire. In the eastern half, intensive frost action during periglacial conditions in the Pleistocene has distributed dolerite debris downslope from the capping sills on most of the topography. As a result, clay minerals are incorporated in many soils on sedimentary exposures. The influence of weathering and solution of the geological substrate and concentration due to low precipitation/evaporation (P/E) ratios are evident from input–output differences in the streamwaters from the catchments shown in table 6 and the outflow concentration in table 7.

Input of Nutrients in the Precipitation (Cyclic Salt)

There are few data on the nutrient content of rainwater in Tasmania. Adams & Attiwill's (1988) data from northern Tasmania are the sole available source of information on inputs in precipitation from which attenuation of the elemental concentrations with distance from the coast can be derived. The set of data from the Cape Grim weather station (Ayers & Ivey 1988) provided an indication of the high maritime influence in the west. Data for eight years showed mean precipitation 794 mm, wind direction 63% westerly, wind velocity 6–17 m/sec 80% of time, mean velocity 11–12 m/sec, mean input of elements in kg/ha: Na 267, K 11.8, Ca 15.6, Mg 30.0. In view of the strength of the westerly airstream and the generally rougher seas in the west, it could be expected that the inputs of aerosols would be higher and the transport of nutrients inland would be higher in the west than in the east. It is expected, therefore, that the data of Adams & Attiwill (1988) are unlikely to be applicable to western environments. To provide some estimates of the attenuation of nutrient concentration with distance from the western coast, data on the concentration of nutrients in very small natural catchments, such as lakes and tarns surveyed by Buckney & Tyler (1973), have been utilised to create approximate precipitation inputs. The catchments used are rock basins at high altitudes on hard dolerite or quartzite. The areas drained are all less than a few square kilometres and carry heathy vegetation and shallow peaty soils. The waters have totally dissolved solids ranging from 20–40 ppm. These data are summarised in figure 2B for eastern environments using Adams and Attiwill's (1988) data and in figure 2A for western environments using Buckney & Tyler's (1973) data as an approximation. Exponential curves have been fitted to both data sets with respective correlation coefficients. The data collected over

TABLE 6
Nutrient balance (NB kg/ha/yr) and difference in concentration (CD ppm) both input–output

Catchment*	Prec. mm	Evap. %	Dist.* km	C* no.	Yr* no.	Na NB	Na CD	K NB	K CD	Ca NB	Ca CD	Mg NB	Mg CD
Victorian data													
Cropper Ck, Myrtleford	1200	94	180	1	1	+1.56	–1.37	+1.44	–0.23	+3.02	–0.01	+0.40	–0.77
loam/shale *E. radiata*	1200	90		2	1	+1.29	–1.33	+1.47	–0.18	+2.82	–0.08	–0.05	–0.88
(Flinn *et al.* 1979)	1200	85		3	1	+0.06	–1.79	+1.27	–026	+2.16	–0.70	–0.92	–1.51
Stewarts Ck, Daylesford	1094	83	115	1	1	+13.2	–1.17	+7.30	–0.18	+1.60	–0.11	–0.10	–0.08
loam/shale *E.obliqua*	1360	73		1	2	–5.80	–5.86	–0.10	–0.45	+0.80	–0.00	–3.50	–1.00
(Guthrie *et al.* 1978)	1432	73		1	3	–13.2	–5.74	–1.00	–5.91	+0.80	–0.02	–3.10	–1.03
Maroondah c Healesville	1554	66	100	1	1	–7.68	–3.06	–2.03	–0.93	–6.65	–1.78	–2.09	–0.68
kraznozem/granite *E. reg.*	1514	47		1	2	–6.91	–2.02	–4.28	–0.57	–3.42	–0.76	–2.68	–0.48
(Feller 1981)	1495	51		2	1	–22.44	–4.09	–5.19	–1.04	–12.69	–2.60	–4.70	–0.77
	1462	43		2	2	–18.26	–2.74	–6.63	–0.67	–6.16	–0.88	–5.91	–0.76
Tasmanian data† (Buckney & Tyler 1973)						input kg/ha	CD ppm	input kg/ha	CD ppm	input kg/ha	CD ppm	input kg/ha	CD ppm
Forester R. Dss *E.obl.*	1200	87	20			21.0	–0.80	3.0	–0.71	14.4	–0.69	3.8	–0.19
Lisdillon Rvl. Jd *E.glob.*	650	130	8			17.9	–20.2	2.3	–0.51	7.8	–12.84	2.6	–0.98
George R. D. granite rf/ws	950	86	26			13.3	–0.59	5.4	–0.85	11.4	–1.21	1.9	–0.21
Picton R. Pls.*E.obl.*ws/rf	1800	41	36			72.9	–1.60	11.2	–0.16	14.4	–3.92	9.0	–0.94
L St Clair Jd/Pms *E.del.*/rf	1700	40	70			32.3	–1.12	10.0	–0.43	13.6	+0.02	5.1	+0.16
Yolande R. Cvolc rf	3500	21	26			127.5	–0.55	26.3	–0.19	28.0	–0.12	17.5	–0.34
L. Pedder. Pcqrtz till sedgel	2700	28	40			64.8	–0.41	16.7	+0.11	23.0	+0.08	13.2	–0.46

* C = catchment, yr = year, dist. = distance from coast.
† Pms = Permian mudstone, Pls = Permian limestone, Jd = Jurassic dolerite, Dss = Devonian siltstone, Cvolc = Cambrian volcanics, Pcqrtz = Precambrian quartzite, rf = rainforest, ws = wet sclerophyll.

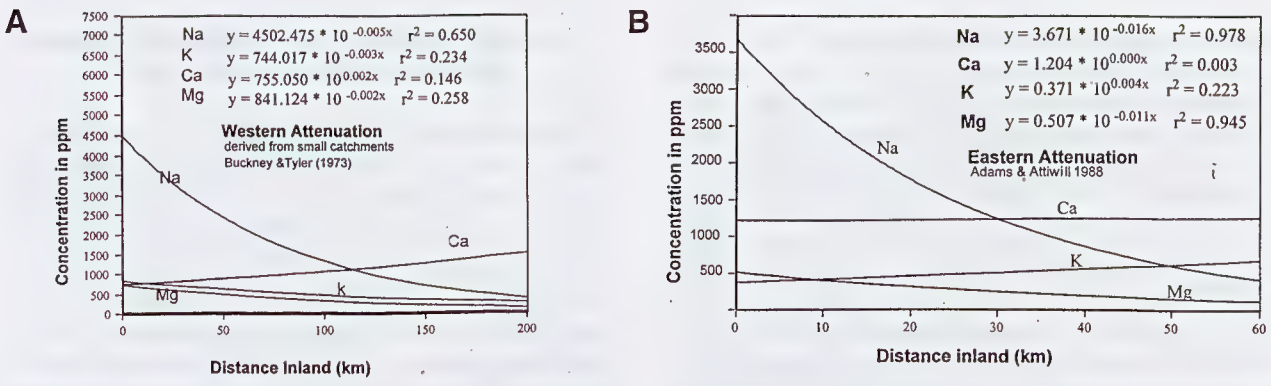

A
Na y = 4502.475 * 10 -0.005x r2 = 0.650
K y = 744.017 * 10 -0.003x r2 = 0.234
Ca y = 755.050 * 10 0.002x r2 = 0.146
Mg y = 841.124 * 10 -0.002x r2 = 0.258
Western Attenuation
derived from small catchments
Buckney &Tyler (1973)
Concentration in ppm
Distance inland (km)
B
Na y = 3.671 * 10 -0.016x r2 = 0.978
Ca y = 1.204 * 10 0.000x r2 = 0.003
K y = 0.371 * 10 0.004x r2 = 0.223
Mg y = 0.507 * 10 -0.011x r2 = 0.945
Eastern Attenuation
Adams & Attiwill 1988
Concentration in ppm
Distance inland (km)

FIG. 2 — Attenuation of nutrients in the precipitation with distance inland. (A) in western Tasmania; (B) in eastern Tasmania.

TABLE 7
Outflow concentrations of nutrients for sample geological exposures in parts per million*

Princ. geological exposure	catchment	Vegetn†	Coordinates‡	Precip mm	Evapn mm	p/t	Elemental concn ppm TDS§	Na	K	Ca	Mg
Igneous rocks											
Tertiary. basalt	Fossey R..	ws/rf	8015845102	2050	750	2.7	34	3.3	0.9	1.1	1.2
Tertiary. basalt	Hatfield R.	ws/rf	8014883018	2100	750	2.8	33	2.8	0.4	1.4	1.3
Jurassic dolerite	Derwent R.	ws/rf	8113391200	1900	750	2.5	25	2.2	0.7	0.4	0.3
Jurassic dolerite	Great Lake	gf/mont	8214785605	1050	1000	1.05	20	1.3	0.3	1.3	0.7
Jurassic dolerite	Lake Leake	*E. del* gf	8413659491	870	1000	0.87	42	3.7	1.5	2.2	1.4
Jurassic dolerite	Lisdillon Rvl.	*E. glb* ds	8413819180	725	1200	0.6	174	23.9	2	15	9.9
Camb.acid volcanics	Que R.	rf	8015902963	2200	750	2.9	36	3.1	0.8	2.6	0.7
Camb.acid volcanics	Macintosh R.	ws/rf	8015853802	2200	750	2.9	37	2.2	0.7	0.6	0.3
Camb.acid volcanics	Yolande R.	rf	8013769470	2600	750	3.4	28	2.8	0.6	0.9	0.9
Devonian granodiorite	South Esk R.	*E. del*.f	8415741092	1200	1000	1.2	32	3.4	0.4	1.6	1.3
Devonian granodiorite	St Patricks R.	*E. del*.f	8315347283	1250	1100	1.1	38	3.3	0.6	1.8	1
Devonian adamellite	Groom R.	rf	8515848348	1200	1100	1.1	51	5.9	0.9	1.1	1
Cambrian serpentine	Sawback Ck	ws/rf	8112457655	1300	800	1.6	42	3.1	0.6	1.9	3.9
Calcareous sediments											
Perm. peb.mudstone	Blackfish Ck	ws	8015882587	1100	1150	1.0	81	8.9	2.5	3.2	3.1
Permian limestone	Picton R.	ws/rf	8211762270	1300	900	1.4	92	3.9	0.5	4.3	1.6
Perm. mudst/limest	Sandfly Ck	d/ws	8312142392	700	1200	0.6	87	3.5	0.5	31	15.2
Ordovician limestone	L. Florentine R.	rf	8112527679	1200	900	1.3	152	3.1	0.5	35.2	19.1
Precamb. dolomite	Weld R.	rf	8112545597	1300	900	1.4	211	4.3	11.8	40	25
Siliceous sediments											
Dev. quartzwacke	Forester R.	ds	8415523557	785	1100	0.7	42	3.4	1.0	1.0	0.9
Camb.greywacke	Whyte R.	rf	7915657080	2100	750	2.8	57	4.3	0.3	2.2	2.7
PC orth/m quartzite	Louisa R.	sgl	8111522844	1600	800	2.0	72	6.6	1.4	1.5	1.8
Dev.quartzite/ sst	King R.	sc/rf	8013890400	2500	750	3.3	30	2.2	0.5	1.8	0.8
PC. metaquartzite	Murchison R.	sgl/rf	8014854754	2150	750	2.9	33	1.8	0.5	0.9	0.4
PC. metaquartzite	Ck L. Pedder	sgl	8112320427	2600	600	4.3	38	2.9	0.3	0.5	0.5

* Reference: Buckney & Tyler (1973)

† ws = wet sclerophyll, ds = dry sclerophyll, rf = rain forest, gf = grassy forest, mont = montane heath, sgl = sedgeland, sc = wet scrub, *E. del* = *Eucalyptus delegatensis*, *E. glb* = *Eucalyptus globulus*.

‡ Co-ordinates — the first four digits form the number of the relevant Tasmap 1:100 000 map sheet; this is followed by three digit eastings and northings.

§ TDS=total dissolved solids

two years by Adams & Attiwill show excellent fits to the data for Na and Mg and very poor fits for K and Ca, with both showing no apparent attenuation. The approximate data for the western environments have reasonable fits by the exponential curves considering their source. Again, the fit for Ca is poor and the suggested attenuation is positive. The fit for K is reasonable compared with that in the east. The prediction curves shown in figure 2A, B should provide some guide as to inputs in precipitation. The ordinate at any distance in ppm x precipitation in mm $\times 10^{-2}$ = input in kg/ha/yr. As expected, there is a considerable difference in the predicted attenuation rates between the western and the eastern environments. The data for Cape Grim and Port Davey would indicate a very rapid attenuation in the first 10 km from the western coast, so that zero distance on the western attenuation curves represents the input at about 10 km inland. On the basis of the prevailing source of the wind-borne precipitation, environments south of the Derwent River have been treated as westerly, while environments north of the Derwent and east of the Central Plateau are treated as easterly.

Nutrient Balance and Difference between Input and Output Concentration

It might be assumed that the relatively large inputs of nutrients in the rainfall are available to the plant communities or can be accumulated in the soil. However, a study of the balance between inputs and outputs, discussed below, shows that accumulation is far more likely in the eastern environments with low P/E ratios, and that the western environments with high P/E ratios lose nutrients as fast as they enter, so that accumulation is minimal. The impact of fire in mineralising nutrient capital in the vegetation and litter is, therefore, likely to be very much greater in western environments than in eastern ones, due to the high losses through erosion and leaching of ash residue (fig. 2).

No complete nutrient cycling studies determining the nutrient balance (input–output) for a watershed have been conducted in Tasmania. Such studies involve the measurement of input and output volumes as well as input and output masses of elements. There are three studies of catchments in Victoria which supply data probably relevant to catchments in eastern Tasmania (Guthrie *et al.* 1978,

Flinn *et al.* 1979, Feller 1981). These have been summarised in tables by Attiwill & Leeper (1987: 137–139) and by Attiwill *et al.* (1996: table 3). In general, these studies show that the order of loss is Na >> K > Mg > Ca, with some catchments showing small accumulation of Ca. Comparisons of catchments and years indicate that the nutrient balance is still responsive to the P/E ratio, even though it removes the direct effect of evapotranspiration in increasing the concentration of outputs, so that losses of elements tend to increase as the P/E ratio rises. As a result, it would seem that the Victorian data on nutrient balance are unlikely to be applicable to the western and southern regions of Tasmania, where P/E ratios are high and the vegetation and soil are wet much of the time, due to the trend to uniform rain in all seasons (Jackson 1999b) and to high reliability (Scott 1956).

Data on the difference between input–output in elemental concentration are available for a few catchments in Tasmania from the work on water chemistry by Buckney & Tyler (1973). These data are limited to comparisons of concentrations in extremely small headwater catchments with downstream concentrations and to single sampling in time. As such, they must be regarded as only an approximate guide to the relative size of the input and output concentrations for the catchments. Since no volume measurements are available for river flows, the data can only be expressed in concentrations (ppm). Table 6 shows the data for the above Victorian catchments for nutrient balance and the difference between input and output concentration for a selection of Tasmanian catchments. The combined data allow a better interpretation of the very different environments across Tasmania. It appears from the collective data for Victoria in table 6 that nutrient accumulation generally increases in drier years, and that losses are greater in wet years so that the nutrient balance does not entirely account for all the evapotranspiration.

The apparent increase in accumulation in the drier sites and years demonstrated by the Victorian data for nutrient balance seems to indicate the conversion of elements into poorly soluble pools in proportion to the long residence-time in the catchments. The opposite tendency for increasing losses in wetter years and catchments probably reflects the flushing of accumulated nutrient in the wetter conditions. The increasing losses in wet years or catchments does not extend to wet environments in Tasmania. The data for difference between input–output concentrations clearly show that, in the very wet environments, the difference in concentration between input–output decreases to zero for elements like K and Ca while Na and Mg have very low differences of < 0.5 ppm.

The parallels between the data on nutrient balance and the difference in input–output concentrations allow some limited application of the Victorian data to Tasmania. It is possible to obtain a rough guide to the effects of P/E ratio, marine influence, geological substrate and vegetation. The small positive difference in K and Ca at Lake Pedder for instance reflects the high demand for these elements by the *Gymnoschoenus* and the heath community respectively. The table of concentration differences in inflow–outflow provides useful information on the nutrient environment. For instance, the high P/E ratio in the west provides an input to the Yolande catchment of 127 kg/ha/yr of Na with a balance of only 0.55 ppm, whereas the low P/E ratio in the east provides an input of 18 kg/ha/yr of Na for Lisdillon catchment, with a difference between input–output of 20 ppm, indicating the effect of high evapotranspiration concentrating the run-off. In contrast, in the western environments the vegetation is awash with water and nutrients which it cannot retain. This means that large erosion and leaching losses must occur following mineralisation of the above-ground vegetation by fire in these wet environments. The very approximate estimates derived from data by Buckney & Tyler (1973), shown in table 7, indicate the likely information on nutrient availability in Tasmanian watersheds, due to differing precipitation/evaporation ratios and the degree of weathering and solution of geological substrates which could be obtained from the collection and analysis of rainwater and catchment outflows.

In summary, it appears that the input of nutrients to the soil and vegetation in Tasmania derived from precipitation as cyclic salt and aerosols probably exceeds the input to most watersheds from the weathering of the geological substrate, the possible exceptions being those of basaltic exposures. The climate in Tasmania has been dominated by the marine influence and westerly airstream in all past climates of the Pleistocene, and the low average subsoil temperatures would limit chemical weathering rates. It could be expected, therefore, that the input from weathering in Tasmania is likely to be less and the input from precipitation would be greater than corresponding inputs elsewhere in southeastern Australia.

Peat and Duff Fires

Peat and duff fires are reasonably common in the cooler wetter climates of Tasmania during periods of extended drought. Peat fires in 1961/62 burnt nearly 128 000 ha of the Central Plateau (Mitchell 1962). As a consequence of this fire, approximately one-third of the surface has lost 5–10 cm of top soil over the subsequent 20 years through sheet erosion (Jackson 1973, Kirkpatrick & Dickinson 1984b). Duff fires in rainforests in the Frenchmans Cap and Mt McCall regions and in the Denison Range have caused serious erosion in the last twenty years. On this evidence, the damage incurred by duff and peat fires must be significant over the period of a millennium. Elements such as N and P are predominantly cycled in the foliage pool. The upper 10 cm of most organic soils contain 80–90% of the content of the total pools (Adams & Attiwill 1988). The consumption of this upper soil zone, therefore, must have a serious impact on future fertility of the site, especially if followed by erosion. The reduced potential of the soil to capture and retain nutrients from the precipitation input is an important factor in limiting the long-term rebuilding of the productivity of the site. Unfortunately, there is little quantitative evidence of leaching loss following peat or duff fires. The only evidence is for losses in a peat fire in the sedgeland/heath at Condominium Creek in the Southwest where 20 cm of the surface peat were consumed. The pulse of nutrients leached from the ash, as demonstrated by the analyses of Maclean (1979), moved large quantities of Fe and K down the profile to be fixed in unavailable states in clay zones of the lower profile, increasing concentrations in these zones two- to three-fold over the three years succeeding the fire. Elements such as Ca, Mg and P appear to pass right through the profile (Maclean 1979, Bowman & Jackson 1981, Bowman *et al.* 1986).

Nutrient Losses due to Fire in Forest

Hot wild-fires usually completely kill most, if not all, trees in rainforest and wet sclerophyll forests, so that regeneration is normally wholly dependent on establishment from seed (Gilbert 1959, Barker 1991). Although the potential losses of nutrients in intense wild-fires are high (table 5) relative to the total pools before such fires (for P, 76% in rainforest and 88% in wet sclerophyll), there are, on the average, long intervals in which the nutrient pools are replenished from inputs from the precipitation and weathering of the geological parent material. In low-intensity fires, the nutrients, especially P, are mobilised in the ash bed. As Adams & Attiwill (1988, Attiwill *et al.* 1996) pointed out, the remaining pool of living organisms in the organic upper soil usually prevents serious leaching of the ash bed, although losses through erosion can be serious.

The consequences of losses of elements in high demand by dominant plants (table 3) can cause changes in vegetation structure over generations. Rainforest species have higher demand for N and P than eucalypts. Considerable volatile losses of both N and P occur in hot fires, and losses of P by transport of ash are potentially serious (Raison *et al.* 1985b), since P is only acquired very slowly from inputs in precipitation and weathering (table 5). The input of N in precipitation (table 5) supplies some replenishment over time. However, the main source is symbiotic fixation. In eucalypt forests, symbionts in *Acacia* species and possibly of the Rhamnaceous understorey are variable components. In rainforests, very high levels of N fixation occur, due to the epiphytic layers of lichens and mosses in the canopy. It is estimated that these fix N at the rate of about 35–45 kg/ha/yr in Tasmanian rainforests and mixed forests (Parker 1982: table 7.1, p.139). In wet sclerophyll, the rate of fixation falls to 2–6 kg/ha, so there is a large drop in N fixation if a mixed forest is burnt and replaced predominantly by eucalypts.

There has been considerable controversy in the past over the time required for the replacement of nutrients lost from Tasmanian forests due to harvesting by clear felling followed by hot slash-fire to established regeneration (Raison 1981, Neilsen & Ellis 1981). This problem cannot be resolved until detailed nutrient data are collected. Adams & Attiwill (1988) proposed that replacement of all nutrients lost from northeastern forests as a result of logging and regeneration fires was conservatively estimated to occur within 80–100 years from precipitation and weathering. Ellis & Graley (1983) proposed that replacement could be expected within 15–20 years in the southern forests. The latter estimate appears most unlikely, in view of the probable erosion and leaching losses in this wetter environment. In any case, changes in nutrient supply ratio relative to requirements of the regenerating vegetation is a more important issue.

In dry sclerophyll, the losses relative to pre-fire pools are potentially high, e.g. for P about 80% (table 5). Since the intervals free of fire are much shorter, there is a greater drain on nutrient resources. For example, the estimated potential losses of 84% in the consumable mass of P in the *E. amygdalina* dry sclerophyll forest in table 5 must represent a serious cumulative limitation to productivity. This forest was burnt by a fire which defoliated the canopy two years before assessment by Adams & Attiwill (1988). The main consequence of short-interval recurrent fire regimes is to foster a change from understoreys of woody shrubs to "grassy-sedgy" understoreys. These monocot understoreys have underground energy stores and are capable of rapid vegetative recovery. Their presence further shortens the fire-free interval and creates a serious threat to the growth rates of eucalypt regeneration, as for instance in *E. delegatensis* forests (Ellis 1986).

In low P/E environments, where regeneration is readily obtained without the use of fire, its use even for fuel reduction promotes pyrogenic monocot or bracken understoreys, with associated deterioration in fertility (Boerner 1982). The current management policy of the forest industry of using hot slash-burning to create a highly mineralised ash-bed effect for regeneration in high P/E environments also needs to be questioned, especially when applied to low fertility sites. The potential losses of nutrients by erosion and leaching can be serious (tables 5, 6 & 7; see also discussion of results of Lockett & Candy 1984 by Jordan *et al.* 1992).

Nutrient Losses due to Fire in Non-forest Communities

As table 5 indicates, the non-forest communities of scrub, heath and sedgeland have lower soil nutrient reserves. The shorter fire-free intervals in non-forest communities places them at far greater risk of nutrient depletion and, with the exception of grassland, the generally lower microbial content of the soils renders them vulnerable to leaching loss. Many of the soils of heaths and most of the sedgeland peats are acid and anaerobic with high water-tables at least in some seasons. As a consequence, the cation-exchange capacity is low. This is not the case with grassland soils, which are well drained and have high cation-exchange capacity.

Heathland

On the basis of foliar concentrations Australian heath plants have lower nutrient status than other heaths (Specht 1969). The pools of soluble inorganic N and P in the soil form a small proportion of the total pools and are in many cases unrelated. Most of the soil analysis in the early literature (pre 1980) measured total pools. A somewhat different picture is found when the available pools are assessed. Adams *et al.* (1994) showed that, when extractable labile N and P were determined, the surface organic soils of the heaths on Wilsons Promontory, Victoria, were comparable in availability of P and N with soils of most eucalypt forests; also that the concentration of carbon, nitrogen and potentially mineralised nitrogen and phosphatase activity were greater in soils from unburnt heathland than in soils from heath sites repeatedly burnt. In contrast, the concentrations of available P were greater in soils from repeatedly burnt sites (8–10 yrs) than from unburnt sites (~40 yrs). These effects were limited to the surface 2 cm of the soil. The sustained increase in available P and decrease in available N on frequently burned heathland is attributed to a reduction in the concentration of organic matter. The loss of N on frequently burnt sites is in excess of total inputs and constitutes a significant reduction in N stocks.

The findings of Adams *et al.* (1994) should be applicable to most coastal and near coastal heaths in northern and eastern Tasmania and the islands of Bass Strait. It is likely that similar losses of N are serious on the wet heaths in montane and western regions. Maclean (1979) argued that the repeated fires on sedgeland/heaths favour the

development of sedgeland, because of the loss of the divalent cations Ca and Mg which are required by heath plants (Maclean 1979, Bowman *et al.* 1986).

Sedgeland

All the sedgeland plants have extremely low foliar nutrient concentrations. The common Tasmanian species would appear to have nutrient levels well below most plants treated in the literature. *Gymnoschoenus,* which dominates the sedgeland heaths over 40% of western Tasmania (table 1), is remarkable in withdrawing very high amounts (94%) of P and K from the foliage during senescence and then retaining the old foliage on the plant till it slowly decays (table 3). The muck peat formed by the plant is acid, anaerobic and very low in nutrients. Although the peat is high in organic matter, it has very low cation-exchange capacity. The only element to which the plant responds is K (Maclean 1979). A study of biomass accumulation on different sites by Marsden-Smedley (1998) shows that a steady-state biomass in the southwest on Precambrian parent material of 10 t/ha is achieved after 30 years, whereas on the dolerite soils on the western edge of the Central Plateau, where K levels are much higher in the clayey soils, the biomass was 30 t/ha at 30 years and still increasing. It is almost certain that in the Southwest the loss of approximately 50% of the total nutrient pool of K (table 5) in the consumption of the above ground biomass every twenty five years maintains the low production of *Gymnoschoenus* sedgeland.

CONCLUSIONS

The overall evidence suggests that in lowland eastern Tasmania, where P/E ratios are low, the net losses of nutrients after fire are not as great as might be expected in view of the high average frequency of fire in that environment. There are several reasons for this: (a) the fuel loads are lower so the fires are lower in intensity; (b) the vegetation is highly adapted to recurrent fire, recovering both vegetatively and from fire-promoted release and germination of propagules; (c) in the lower rainfall, the regenerating plants take up the mineralised nutrients in the ash-bed before serious erosion or leaching occurs; and (d) the high clay content of dolerite soils binds leached nutrients in unavailable forms which can, over time, become available to the vegetation. In contrast, in western and southern environments of high P/E ratios the vegetation consists of forests poorly adapted to fire and of sedgeland/heaths well adapted to recurrent fire. The palaeovegetation evidence (Jackson 1999d) shows that the sedgeland/heath is a response to the higher frequency of fire resulting from human presence since the Late Pleistocene. The data on differences in input–output concentration nutrients in western watersheds indicate that, in the present interglacial climate, the nutrients in vegetation mineralised by fire are liable to be lost to the run-off water, because in the high rainfall–low evaporation climate the soils are saturated most of the time. There are few clay minerals in most soils in the west to prevent loss by leaching or to capture the relatively large inputs in the precipitation. The vegetation is awash with water and nutrients which it cannot retain. Thus, the nutrients in mineralised ash will largely be lost. The effect of gravitational loss of soil nutrients is a pervading feature of western landscapes (fig. 1). In the present fire regimes, the sedgeland community has little, if any, chance of succession towards forest, and the forest communities are at constant risk of sedgeland advance.

Since the incidence of natural lightning-induced fire in Tasmania is extremely low (Jackson & Bowman 1982, Ingles 1985), the problems of fire incidence are human ones. With the vastly improved access to remote areas, these problems can only increase. Most of Tasmania has been burnt by extensive landscape scale wild-fire once or twice in each of the last two centuries (Marsden-Smedley 1998). Because such fires occur in extreme fire-danger conditions during periods of drought when fuels are exceptionally dry, the fires are intense and extensive. Estimates of nutrient loss in such intense fires are made in table 5. These losses added to the losses of nutrients incurred in each rotation of forest crop outweigh the likely rate of nutrient retention from precipitation and weathering. Hence, there is an economic need to conserve nutrients by reducing the incidence of wild-fire and by reducing the losses due to the deliberate use of fire. This need is over and above the need to protect our visual wilderness and the direct loss of assets in forests (Jackson & Brown 1999). The widespread use of fuel-reduction burning is clearly not the answer, since this only causes further losses of nutrients and fosters changes in the vegetation towards finer fuels with vegetative reproduction. As Boerner (1982) has emphasised, the replacement of the normal shrub storeys with such pyrogenic plants leads to increasing frequency of fire and consequent decrease in soil fertility. One measure which might be taken to reduce the extent of wild-fire in Tasmania would be to maintain bands of low fuel loads in sedgeland adjoining forests by regular patch-burning following Aboriginal traditions in conditions where the fire will not enter the scrub boundary (Nicholson 1981, Marsden-Smedley 1998).

Slash-burning of cut-over forests in regions of high P/E ratios should not be used to regenerate forest crops, in view of the potential losses by erosion and leaching inferred by the data on differences in input–output concentration of elements (table 6) in these wet environments. The need for hot slash-fire in high P/E ratio environments should be reassessed in view of the potential nutrient losses. Leaving slash to decay naturally in these wet environments does not present a fire hazard and would conserve nutrients and the understorey diversity without the risk of accidental escape of fire.

There is an obvious paucity of data on which to base an important resource industry for Tasmania. The effects of forest practices on soil fertility, plant diversity and pyrogenic developments in understorey composition need to be systematically assessed.

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IMPACTS OF LOGGING ON AUTUMN BIRD POPULATIONS IN THE SOUTHERN FORESTS OF TASMANIA

by Andrew B. Hingston

(with four tables, one text-figure and two appendices)

HINGSTON, A.B., 2000 (31:xii): Impacts of logging on autumn bird populations in the southern forests of Tasmania. *Pap. Proc. R. Soc. Tasm.* 134: 19–28. ISSN 0080-4703. Geography and Environmental Studies, University of Tasmania, GPO Box 252-78, Hobart, Tasmania, Australia 7001.

Bird assemblages were documented in different forest types in the Warra Long Term Ecological Research Site in Tasmania's southern forests. Sampling was undertaken in areas immediately after clearfelling and burning, in regrowth up to 26 years after this treatment, in selectively logged forest, in regrowth following wildfire, and in old-growth forest. It was found that areas subjected to clearfelling and burning supported assemblages which were distinct from areas with other histories, in that they comprised fewer species and individuals. This adverse impact of silvicultural practices on bird populations was apparent in all strata of the forest; canopy, mid-layer and ground. Immediately after clearfelling and burning, coupes were colonised by ground-feeding insectivores more typical of open country than of the surrounding wet sclerophyll forests, but these were quickly displaced with the advent of young regrowth, which was gradually colonised by forest-inhabiting species. However, these assemblages were still depauperate as much as 26 years after clearfelling. Comparisons with previous studies suggest that this deleterious impact of forestry operations on birds may be ameliorated by the retention of patches in logging coupes. This is supported by the absence of significant impacts on birds in parts of the area which were selectively logged 25 years earlier.
Key Words: silviculture, forestry, fire, regrowth, Tasmania

INTRODUCTION

Previous studies have found dramatic decreases in bird populations following clearfelling of eucalypt forests in Tasmania (Green 1977, Coulson & Coulson 1980, Dickinson *et al.* 1986, Taylor *et al.* 1997) and other parts of Australia (Loyn 1980, Smith 1984, Kavanagh *et al.* 1985, Recher *et al.* 1985, Smith 1985b). However, some species of birds more typical of open country may increase in abundance after clearfelling (Green 1977, Loyn 1980, 1985, Kavanagh *et al.* 1985, Dickinson *et al.* 1986), but such species are rapidly excluded in regenerating vegetation (Kavanagh *et al.* 1985, Loyn 1985) as the original bird communities re-establish (Coulson & Coulson 1980, Smith 1984, Kavanagh *et al.* 1985). Those inhabiting undergrowth are particularly adept at recolonisation of dense young regrowth (Loyn 1985, Smith 1985a, b). As the regrowth develops, other species return, with bird communities in regrowth wet sclerophyll forests 30–40 years after logging sometimes being fairly similar to those in mature forests. However, several species were still less common in regrowth forest of this age than in mature forest in Victoria (Loyn 1985).

The impact of forestry operations on bird populations may be lessened in Tasmanian dry sclerophyll forests by retaining trees in logged coupes (Taylor & Haseler 1995, Taylor *et al.* 1997). In Western Australian eucalypt forest, selective logging, which removed less than two-thirds of the existing canopy, had little effect on bird populations (Abbott & van Huerck 1985).

The research described here aimed to quantify the effects on birds of the standard silvicultural treatment for wet forests (clearfelling followed by high intensity burning) in the Warra Long Term Ecological Research Site in Tasmania's southern forests. In particular, the capacity for birds to recolonise logged coupes was examined by comparing populations in different ages of silvicultural regeneration. The impact of the standard treatment was also compared to the effects of selective logging and wildfire.

METHODS

Birds were surveyed, between 7 April and 28 May 1998, in coupes of varying ages and silvicultural treatments in Tasmania's southern forests, along Warra Road and South Weld Road. Thirty-three sites, all centred 50 m from the road edge, were categorised into three different treatments according to their silvicultural histories and current vegetation. These were defined as: old-growth (sites O1 to O13); regrowth (sites R1 to R5), encompassing forests which were selectively logged approximately 25 years ago without being subjected to high intensity regeneration burns, and regrowth forests resulting from wildfire; and silvicultural regeneration (sites S1 to S15), which included all areas subject to clearfelling followed by a high intensity regeneration burn between zero and 26 years ago. Sites representing the different treatments were scattered thoughout the survey area as much as possible in order to minimise any local geographic variation in bird assemblages since this, if present, would have confounded the results.

Forest Types and Silvicultural History

The study area was dominated by *Eucalyptus obliqua* L'Herit wet sclerophyll forest. However, a xeric to mesic vegetation gradient was apparent. The most xeric areas carried *E. nitida* Hook. f. over a dense sclerophyllous scrub. This graded into low *E. obliqua* forest with a sclerophyllous understorey, then into taller *E. obliqua* with a broad-leaved understorey. In the more mesic sites *E. regnans* F. Muell. or *E. delegatensis* R.T. Baker sometimes grew alongside *E. obliqua,* and the wettest sites supported mixed forest.

Most of the old-growth sites (sites O1 to O13, numbered from most xeric to most mesic) were last burnt in 1934, although the three most mesic sites had not been burnt since 1898. All of the regrowth forests (sites R1 to R5, numbered from most xeric to most mesic) were burnt in

1934; the difference between these sites and old-growth burnt at the same time apparently due to different fire intensities. Two of these sites, R2 and R3, were also logged in the early 1970s for pulpwood and sawlogs with seed trees retained. Attempts to burn these sites in 1973 failed, but they were burnt in 1977, when a regeneration burn in a nearby clearfelled coupe escaped. Silvicultural regeneration sites (S1 to S15, numbered from youngest to oldest) were divided into two categories according to age. Young silvicultural regeneration included one recently burnt coupe (S1) and four sites (S2–S5)which had been logged between four and six years earlier and carried dense eucalypts 2–5 m in height. Older silvicultural regeneration ranged in age from nine years (S6) to 26 years in age, with eucalypts 6–20 m in height.

It was assumed that the impacts of the three treatments were not confounded by differences in original vegetation types and, hence, bird assemblages. This assumption appeared valid, as the range of plant species appeared reasonably uniform across the three treatments, and both old-growth and regrowth encompassed similar ranges in canopy heights. *E. obliqua* was the most common overstorey tree in most old-growth sites, ranging in height from 30–70 m. Sites O7 and O8 also carried some *E. regnans,* and *E. delegatensis* was also present on site O11. However, O1 differed by carrying *E. nitida* 10 m in height instead of *E. obliqua.* All regrowth forest sites were also dominated by *E. obliqua,* with *E. regnans* also occurring at R5. Sites R2 and R3 carried remnant trees 70 m in height over 15–20 m high regrowth, while R1, R4 and R5 were mostly even-aged trees of 30–40 m. Understoreys in both old-growth and regrowth ranged from sclerophyllous through broad-leaved to rainforest. Silvicultural regeneration was also dominated by *E. obliqua,* with *E. regnans* and *E. delegatensis* also sown on S2, S4, S6 and S7. Where understoreys were beginning to develop after silvicultural regeneration. these comprised a similar range of plants to those in other sites.

Survey Technique

Spot surveys of 15 minutes duration were conducted at each site on fine days with little wind or rain. The daylight hours were divided into five periods of two hours each, with each site being surveyed for birds three times in each period to remove any confounding temporal effects on bird activity. All birds seen or heard within approximately 200 m were noted, with care being taken to exclude birds calling from different vegetation nearby. Birds observed flying over the survey sites well above the height of the vegetation and, therefore, not interacting with it, were excluded from the analysis. However, raptors which flew over the sites were included, as this is their mode of foraging. Golden and olive whistlers were combined in the data analysis, due to difficulties differentiating some of their calls. It was assumed that birds were equally easy to detect in each habitat, and that bird assemblages in areas subjected to the different treatments were independent of each other.

Data Analysis

For each site, the numbers of each bird species recorded were totalled for the 15 surveys. These sites were ordinated using semi-strong hybrid multidimensional scaling (ssh mds) according to their bird assemblages, using the computer programme PATN (Belbin 1993). The bird species which were significant predictors ($p < 0.05$) of the variation between communities at these sites were fitted to the ordination plot as vectors.

Differences in bird assemblages between the three treatments were analysed, using One-way Analysis of Variance (ANOVA) when the data were normally distributed and the non-parametric Kruskal-Wallis Test whenever this assumption was not met. If significant differences between treatments were apparent, pairwise comparisons were then conducted between treatments, using Student-Newman-Keuls Test for normally distributed data and Dunn's Method for non-normal data. The total numbers of individual birds (normal data) and species (non-normal data, $p = 0.0249$) observed at each site during the 15 surveys were analysed in this way. As there appeared to be a major disjunction in the total numbers of species between young (0–6 years old) and older (9–26 years old) silvicultural regeneration (appendix 1), subsequent tests were used to investigate differences in species richness (normal data) and the numbers of individuals (non-normal data, $p = 0.0239$) between these two treatments, regrowth and old-growth.

The same statistical technique was used to investigate the differences between the three treatments in the total numbers of individuals of each bird species observed at each site during 15 surveys. The total numbers of birds in each foraging guild observed at each site was also investigated in this way. Guild allocations were based on the height at which most foraging was undertaken, and were the same as those used by Taylor & Haseler (1995) and Taylor *et al.* (1997), except for the brown goshawk and green rosella, which were classed as canopy-feeders here. Hence, the guild allocations were:

(1) canopy:
spotted pardalote *Pardalotus punctatus*
striated pardalote *P. striatus*
black-headed honeyeater *Melithreptus affinis*
strong-billed honeyeater *M. validirostris*
yellow wattlebird *Anthochaera paradoxa*
black-faced cuckoo-shrike *Coracina novaehollandiae*
green rosella *Platycercus caledonicus*
sulphur-crested cockatoo *Cacatua galerita*
brown goshawk *Accipiter fasciatus*

(2) mid-layer:
grey fantail *Rhipidura fuliginosa*
brown thornbill *Acanthiza pusilla*
Tasmanian thornbill *A. ewingii*
scrubtit *Acanthornis magnus*
silvereye *Zosterops lateralis*
eastern spinebill *Acanthorhynchus tenuirostris*
crescent honeyeater *Phylidonyris pyrrhoptera*
New Holland honeyeater *P. novaehollandiae*
yellow-throated honeyeater *Lichenostomus flavicollis*
golden whistler *Pachycephala pectoralis*
olive whistler *P. olivacea*
grey shrike-thrush *Colluricincla harmonica*
yellow-tailed black cockatoo *Calyptorhynchus funereus*

(3) ground:
beautiful firetail *Stagonopleura bella*
flame robin *Petroica phoenicea*

pink robin *P. rodinogaster*
scarlet robin *P. multicolor*
dusky robin *Melanodryas vittata*
superb fairy-wren *Malurus cyaneus*
Tasmanian scrubwren *Sericornis humilis*
Bassian thrush *Zoothera lunulata*
superb lyrebird *Menura novaehollandiae*
grey butcherbird *Cracticus torquatus*
black currawong *Strepera fuliginosa*
forest raven *Corvus tasmanicus*
wedge-tailed eagle *Aquila audax.*

For those species and guilds which exhibited significant pairwise differences between abundances in silvicultural regrowth and in other forest types, subsequent analyses were conducted, whereby only silvicultural regrowth greater than nine years old was included.

RESULTS

There were significant differences between forest treatments in the total numbers of individuals ($p < 0.0001$) and species ($p < 0.01$) of birds observed during 15 surveys. Pairwise tests demonstrated that there were significantly fewer individuals and species in silvicultural regeneration than in either of the other two treatments (table 1A, B). Fewer individuals were observed at each silvicultural regeneration site than at any of the other sites (appendices 1, 2). Hence, bird assemblages in silvicultural regeneration were distinct from all others and negatively associated with abundances of most bird species (fig. 1). This difference did not appear to be completely due to lower canopy heights in silvicultural regeneration, because the bird assemblage at site O1, with a canopy only 10 m high, was more similar to that in other old-growth forests than in silvicultural regeneration (fig. 1).

In contrast no significant differences were recorded in the numbers of individuals (table 1A) or species (table 1B) between regrowth forests, resulting from wildfire or selective logging without intense regeneration burning, and old-growth forests. Furthermore, there was substantial overlap in the compositions of bird assemblages in regrowth and old-growth forests, with most bird species being strongly associated with these treatments (fig. 1). Within both regrowth and old-growth forests there were parallel changes in bird communities from mesic to xeric vegetation types (fig. 1A). Wetter forests were typified by the scrubtit, black currawong, pink robin and grey fantail. In contrast, the beautiful firetail, crescent honeyeater and silvereye were characteristic of drier forests (fig. 1).

Of the areas subjected to the standard silvicultural regeneration regime (clearfelling followed by intense burning of logging slash) the site which had just been burnt (S1) was most distinct in its bird assemblage from those in old-growth and regrowth forests (fig. 1A). This bird assemblage was very different to all others, with 24 of the 28 dusky robins, seven of the nine scarlet robins, and three of the 11 flame robins recorded in the whole survey being from this site (appendices 1, 2). The only other birds observed at this site were eight forest ravens, three superb fairy-wrens and one Tasmanian scrubwren (appendix 1).

This difference in bird assemblages, between areas which were clearfelled and burnt and those which were not, gradually declined as silvicultural regrowth aged (fig. 1A). This can be attributed to the significantly fewer species in regeneration aged less than six years compared with that aged between nine and 26 years (table 1C). However, this older age class of silvicultural regeneration was still significantly less species-rich than both old-growth and regrowth forests (table 1C). Numbers of individual birds recorded from older silvicultural regeneration were also significantly lower than from old-growth forests (table 1D).

All bird species which exhibited significant differences in abundance between treatments were less common in silvicultural regeneration than in either old-growth or regrowth forests (table 2). Of the 14 species, ten were significantly less common in silvicultural regeneration than in old-growth forests, and seven were significantly less common in silvicultural regeneration than in regrowth forests resulting from wildfire or selective logging. However, none showed significant differences in abundance between old-growth and regrowth forests (table 2). The differences found cannot be attributed to the inclusion of very young regrowth in the silvicultural regeneration treatment, as all 11 species which were significantly less common in silvicultural regeneration than in old-growth and/or regrowth forests were still less common in older silvicultural regeneration than in either of the other two treatments (table 3). Of these species, seven were significantly less common in older silvicultural regeneration than in old-growth forests and five were significantly less common in older silvicultural regeneration than in regrowth forests (table 3). The birds most severely affected by standard silvicultural practices were the green rosella, grey shrike-thrush, spotted pardalote, Tasmanian scrubwren, yellow-throated honeyeater, silvereye and the whistlers (table 3).

The impact of standard silvicultural practices on bird species abundances was evident in all strata of the forest (tables 2, 3). Total numbers of individuals in each guild were always lower in silvicultural regeneration than either old-growth or regrowth forests (table 2). This difference was significant between silvicultural regeneration and old-growth forests in all three guilds. Birds which fed in the canopy or mid-layer were also significantly less common in silvicultural regeneration than in regrowth forests resulting from wildfire or selective logging without high intensity burning. However, the lower number of ground-feeding birds in silvicultural regeneration than in regrowth forests was not significant. In contrast to the marked differences between silvicultural regeneration and other treatments, there were no significant differences between old-growth and regrowth forests in abundances of birds in any of the guilds (table 2). The differences found cannot be attributed to the inclusion of very young regrowth in the silvicultural regeneration treatment, as exactly the same patterns were apparent when young silvicultural regeneration was excluded from the analysis (table 3).

Only four species which averaged more than two individuals per 15 surveys per site in any given treatment did not exhibit significant differences in abundances between treatments. These were the black currawong, superb fairy-wren, strong-billed honeyeater and yellow-tailed black cockatoo (table 2). Abundances of all these species were characterised by standard deviations greater than their means in at least one treatment, and only one (superb fairy-wren) was more common in silvicultural regeneration than in either old-growth or regrowth forests (table 2).

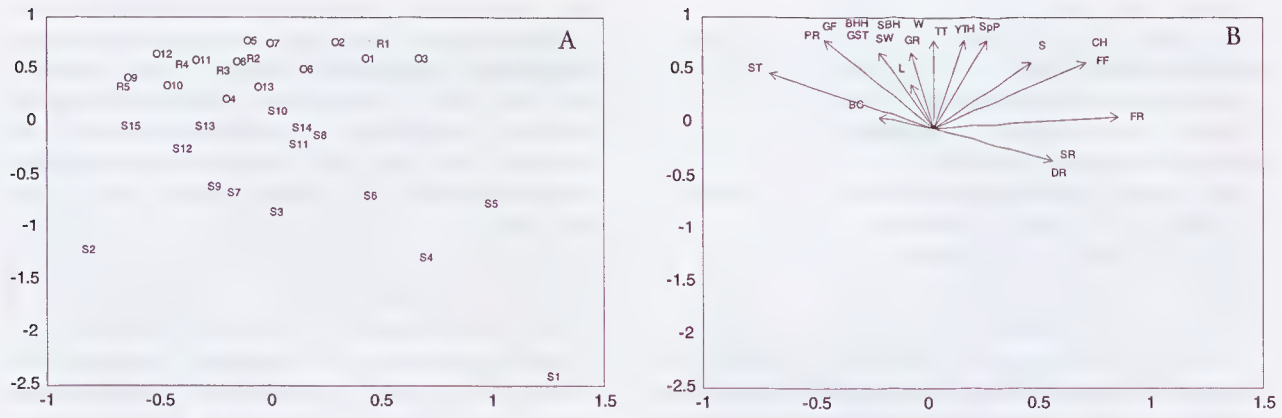

FIG. 1—Relationships between spot survey sites in bird community compositions over 15 surveys. Axes for (A) and (B) correspond for ease of comparison. Stress for 3 axes = 0.129. (A) Ordination of survey sites. (B) Bird species which were significant predictors of the variation between sites fitted as vectors. Species codes are given in table 2.

TABLE 1
Pairwise comparisons based on observations during 15 syrveys at each site*

(A) Total number of individual birds using Student-Newman-Keuls Test

Comparison	Means	q	p
O v. S	252.6 v. 90.6	12.22	< 0.05
O v. R	252.6 v. 246.8	0.316	N.S.
R v. S	246.8 v. 90.6	8.644	< 0.05

(B) Total number of bird species using Dunn's Method

Comparison	Medians	Q	p
O v. S	19.0 v. 16.0	2.507	< 0.05
O v. R	19.0 v. 19.0	0.005	N.S.
R v. S	19.0 v. 16.0	3.410	< 0.05

(C) Total number of bird species using Student-Newman-Keuls Test

Comparison	Means	q	p
0-6 y v. 9-26 y	7.20 v. 17.30	16.97	< 0.05
O v. 0-6 y	19.31 v. 7.20	21.18	< 0.05
R v. 0-6 y	19.20 v. 7.20	17.46	< 0.05
O v. 9-26 y	19.31 v. 17.30	4.393	< 0.05
R v. 9-26 y	19.20 v. 17.30	3.193	< 0.05

(D) Total number of individual birds using Dunn's Method

Comparison	Medians	Q	p
0-6 y v. 9-26 y	38.0 v. 112.0	1.360	NS
O v. 0-6 y	245.0 v. 38.0	4.269	< 0.05
R v. 0-6 y	236.0 v. 38.0	3.303	< 0.05
O v. 9-26 y	245.0 v. 112.0	3.571	< 0.05
R v. 9-26 y	236.0 v. 112.0	2.455	NS

* O = old-growth, R = regrowth, S = silviculture

DISCUSSION

Impacts of Clearfelling on Bird Communities

The depauperate bird assemblages following clearfelling and high intensity burning in Tasmania's southern forests accord with previous studies elsewhere (e.g. Green 1977, Coulson & Coulson 1980, Smith 1984, 1985b, Kavanagh *et al.* 1985, Recher *et al.* 1985, Dickinson *et al.* 1986). This adverse impact of standard silvicultural practices on bird abundances was consistent across all strata of the forest, in contrast to the highly variable results of Taylor & Haseler (1995) in Tasmanian dry sclerophyll forests.

Low numbers of individuals and species of birds in silvicultural regeneration can be attributed to certain components of the vegetation. In a study of 11 eucalypt forest types and one heathland in Victoria and Queensland (Gilmore 1985), positive correlations were found between densities of insectivorous birds and both plant biomass and canopy height. However, the low numbers of birds in silvicultural regeneration in this study cannot be attributed solely to reduced biomass, because more individuals were observed on the unlogged site O1, with a canopy height of only 10 m, than on any of the silvicultural regeneration sites (appendices 1, 2). Over one-third of the individuals recorded on this site were crescent honeyeaters (appendix 2) which fed predominantly from inflorescences of *Banksia marginata* Cav., indicating that the absence of mature populations of certain plant species from silvicultural regeneration contributed heavily to the depauperate nature of their bird assemblages.

Assemblages of birds in older silvicultural regeneration were still distinct from those in old-growth and regrowth forests, even after 26 years. This is consistent with the

TABLE 2
Mean total numbers of individuals of each bird species and guild recorded from sites in each treatment after 15 surveys

Species (code in brackets)*	Numbers†		
	Silviculture	Regrowth	Old-growth
spotted pardalote ^{p} (SpP)	1.40^{a} (1.45)	5.20^{b} (2.49)	4.54^{b} (1.81)
striated pardalote ^{np} (StP)	0.00 (0.00)	0.00 (0.00)	0.15 (0.38)
black-headed honeyeater ^{np} (BHH)	4.07^{a} (6.12)	12.80^{b} (5.59)	8.85^{ab} (5.79)
strong-billed honeyeater ^{np} (SBH)	5.20 (6.37)	9.20 (8.58)	9.62 (6.04)
yellow wattlebird ^{np} (YW)	0.53 (1.55)	0.60 (0.55)	0.31 (0.48)
black-faced cuckoo-shrike ^{np} (BFC)	0.00 (0.00)	0.00 (0.00)	0.15 (0.38)
green rosella ^{np} (GR)	7.20^{a} (5.32)	32.80^{b} (8.41)	38.15^{b} (14.29)
sulphur-crested cockatoo ^{np} (SCC)	0.07 (0.26)	0.00 (0.00)	0.00 (0.00)
brown goshawk ^{np} (BG)	0.27 (0.46)	0.40 (0.89)	0.08 (0.28)
canopy ^{p}	18.73^{a} (16.45)	61.00^{b} (11.51)	61.85^{b} (17.92)
grey fantail ^{np} (GF)	2.40^{a} (2.97)	6.20^{ab} (2.86)	6.23^{b} (3.24)
brown thornbill ^{np} (BT)	0.00 (0.00)	0.00 (0.00)	0.08 (0.28)
Tasmanian thornbill ^{p} (TT)	11.73^{a} (7.46)	22.00^{ab} (10.15)	24.23^{b} (12.13)
scrubtit ^{np} (ST)	2.80^{a} (3.53)	9.40^{a} (6.58)	8.15^{a} (6.74)
silvereye ^{np} (S)	8.47^{a} (5.32)	25.60^{ab} (19.91)	27.69^{b} (14.77)
eastern spinebill ^{np} (ES)	0.87^{a} (3.36)	1.40^{a} (1.67)	2.23^{a} (4.38)
crescent honeyeater ^{np} (CH)	6.93^{a} (5.76)	25.20^{ab} (27.01)	25.08^{b} (22.23)
New Holland honeyeater ^{np} (NHH)	0.00 (0.00)	0.00 (0.00)	0.08 (0.28)
yellow-throated honeyeater ^{np} (YTH)	2.07^{a} (2.43)	13.20^{b} (6.26)	10.69^{b} (3.99)
olive/golden whistler ^{p} (W)	2.93^{a} (2.66)	6.20^{b} (1.30)	8.23^{b} (2.52)
grey shrike-thrush ^{p} (GST)	7.13^{a} (5.88)	19.00^{b} (6.75)	17.77^{b} (4.92)
yellow-tailed black cockatoo ^{np} (YBC)	0.73 (1.16)	2.40 (2.61)	1.69 (1.89)
mid-layer ^{p}	46.07^{a} (28.84)	130.60^{b} (48.43)	132.15^{b} (25.23)
beautiful firetail ^{np} (FF)	0.00 (0.00)	0.20 (0.45)	0.31 (0.63)
flame robin ^{np} (FR)	0.33 (0.82)	0.40 (0.89)	0.31 (1.11)
pink robin ^{p} (PR)	3.53^{a} (3.09)	8.80^{a} (3.27)	8.62^{a} (5.53)
scarlet robin ^{np} (SR)	0.47 (1.81)	0.00 (0.00)	0.15 (0.38)
dusky robin ^{np} (DR)	1.67 (6.18)	0.00 (0.00)	0.23 (0.83)
superb fairy-wren ^{np} (SFW)	5.20 (5.61)	2.80 (5.72)	4.23 (5.61)
Tasmanian scrubwren ^{p} (SW)	4.13^{a} (2.45)	15.80^{b} (5.54)	17.00^{b} (4.32)
Bassian thrush ^{np} (T)	0.27 (0.59)	1.40 (1.67)	0.54 (0.78)
superb lyrebird ^{np} (L)	0.20 (0.56)	0.80 (1.30)	0.62 (0.65)
grey butcherbird ^{np} (GB)	0.07 (0.26)	0.00 (0.00)	0.00 (0.00)
black currawong ^{np} (BC)	8.60 (15.01)	24.20 (37.59)	25.08 (44.06)
forest raven ^{np} (R)	1.33 (2.29)	0.80 (0.84)	1.31 (1.60)
wedge-tailed eagle ^{np} (WTE)	0.00 (0.00)	0.00 (0.00)	0.23 (0.60)
ground ^{np}	25.80^{a} (18.00)	55.20^{ab} (34.51)	58.62^{b} (42.72)

* np = non-parametric tests, i.e. Kruskal-Wallis Test followed by pairwise comparisons using Dunn's Method. p = parametric tests, i.e. 1-way ANOVA followed by pairwise comparisons using Student-Newman-Keuls Test.
† Standard deviations are given in brackets. For birds with significant differences in abundances across the three treatments, significant pairwise differences ($p < 0.05$) are denoted by the superscripts a and b.

numbers of species and individuals in 7–27-year-old regeneration after clearfelling being lower than in mature forest on ridges in Gippsland (Loyn 1980). Similarly, fewer species were found in 10–15-year-old regeneration after logging and burning, (which left only five trees per hectare) than in mature forest on ridges in southeastern NSW (Smith 1985a, b). This was in spite of recolonisation of clearfelled areas by forest-inhabiting birds as the silvicultural regrowth aged, as occurred in other regrowth forests following logging (e.g. Green 1977, Coulson & Coulson 1980, Loyn 1980, Smith 1984, 1985b).

Impacts of Selective Logging and Wildfire

Selective logging 25 years ago followed by wildfire 21 years ago, or wildfire 55 years ago in unlogged forests, did not have significant impacts on bird assemblages. In accord with the present study, similar numbers of species were found in regeneration after selective logging 10–15 years ago and in mature forest in gullies in southeastern NSW (Smith 1985a, b). Smith (1985a) found that a large proportion of species recorded in regrowth spent most of their time in retained trees, and proposed that the number of birds

TABLE 3
Mean total numbers of individuals of each bird species and guild recorded from sites in each treatment after 15 surveys

Species*	Numbers†		
	Silviculture‡	Regrowth	Old-growth
spotted pardalote ^{p}	1.40^{a} (1.58)	5.20^{b} (2.49)	4.54^{b} (1.81)
black-headed honeyeater ^{p}	6.10 (6.67)	12.80 (5.59)	8.85 (5.79)
green rosella ^{p}	9.60^{a} (4.55)	32.80^{b} (8.41)	38.15^{b} (14.29)
canopy ^{p}	26.20^{a} (15.06)	61.00^{b} (11.51)	61.85^{b} (17.92)
grey fantail ^{p}	3.60 (2.99)	6.20 (2.86)	6.23 (3.24)
Tasmanian thornbill ^{p}	15.0 (5.94)	22.00 (10.15)	24.23 (12.13)
silvereye ^{np}	11.00^{a} (2.30)	25.60^{ab} (19.91)	27.69^{b} (14.77)
crescent honeyeater ^{np}	9.20 (5.80)	25.20 (27.01)	25.08 (22.23)
yellow-throated honeyeater ^{np}	3.10^{a} (2.38)	13.20^{b} (6.26)	10.69^{b} (3.99)
olive/golden whistler ^{p}	4.40^{a} (1.96)	6.20^{ab} (1.30)	8.23^{b} (2.52)
grey shrike-thrush ^{p}	10.40^{a} (4.17)	19.00^{b} (6.75)	17.77^{b} (4.92)
mid-layer ^{np}	63.30^{a} (15.61)	130.60^{b} (48.43)	132.15^{b} (25.23)
Tasmanian scrubwren ^{p}	5.30^{a} (2.00)	15.80^{b} (5.54)	17.00^{b} (4.32)
ground ^{np}	25.20^{a} (10.71)	55.20^{ab} (34.51)	58.62^{b} (42.72)

* np = non-parametric tests, i.e. Kruskal-Wallis Test followed by pairwise comparisons using Dunn's Method. p = parametric tests, i.e. 1-way ANOVA followed by pairwise comparisons using Student-Newman-Keuls Test.
† Standard deviations are given in brackets. For birds with significant differences in abundances across the three treatments, significant pairwise differences ($p < 0.05$) are denoted by the superscripts a and b.
‡ excluding silvicultural regrowth less than nine years old.

TABLE 4
Species of birds less abundant in silvicultural regeneration than old-growth or regrowth forests in Warra, and other studies*

Species	Studies
pink robin	1
Tasmanian scrubwren	7 8
scrubtit	1
Tasmanian thornbill	7
golden whistler	1 7 9
grey fantail	1 3 5 7 8 9
spotted pardalote	1 2 3 4 5 6 7 8
crescent honeyeater	1 4 7 8 9
black-headed honeyeater	7 8 9
strong-billed honeyeater	7 8 9
yellow-throated honeyeater	7 8
green rosella	7 8
grey shrike-thrush	2 3 7 9

* Studies which have found similar results elsewhere: codes — 1 = Green 1977; 2 = Loyn 1980; 3 = Kavanagh *et al.* 1985; 4 = Loyn 1985; 5 = Recher *et al.* 1985; 6 = Smith 1985a; 7 = Dickinson *et al.* 1986; 8 = Taylor & Haseler 1995; 9 = Taylor *et al.* 1997.

inhabiting regrowth would have been greatly reduced if trees had not been retained. This opinion is supported by the absence of an impact on the number of species in gullies, where, on average, 12 trees per hectare were retained, while logging on ridges, which left an average of only five trees per hectare, significantly reduced the number of species (Smith 1985a, b). Similarly, in southeastern Tasmania, Taylor *et al.* (1997) found that more bird species occurred in areas of young regrowth where 20–80-year-old trees were retained than in completely clearfelled areas. Hence, the low numbers of birds found during the present study in regrowth following clearfelling compared with selective logging may be due to the almost complete absence of older trees in the former. Another possible reason for the severe impact on birds of clearfelling compared with selective logging is the more intense fires associated with regeneration after clearfelling.

However, the similarity found in this study between bird assemblages in selectively logged and old-growth forests contrasts with the lower numbers of individuals and species found in Gippsland gully forests selectively logged 15 years earlier compared with those unlogged (Loyn 1980). In the Gippsland study, regrowth forests 40 years or more after selective logging and/or wildfire still had less species and individuals than mature forest. The absence of differences in bird communities between regrowth and old-growth forests in the present study may be due to many of the old-growth forests also being burnt 55 years ago, when the regrowth forests were burnt.

Impacts of Clearfelling on Particular Species

Numerous species adversely affected by clearfelling in this study have exhibited similar responses elsewhere (table 4). However, most other studies where silvereyes occurred did not find differences in their abundances between mature forests and silvicultural regeneration (e.g. Green 1977, Kavanagh *et al.* 1985, Loyn 1985, Taylor *et al.* 1997). Indeed, one southeastern NSW study (Smith 1985a) found silvereyes were more abundant in regrowth, where between five and 12 trees had been retained per hectare of logging coupe, than in mature forest.

Uncommon species recorded from old-growth and/or regrowth forests but not from silvicultural regeneration in the present study also exhibited similar patterns in some other situations. Striated pardalotes were much less common in silvicultural regeneration than in mature forest in Tasmania (Dickinson *et al.* 1986, Taylor & Haseler 1995, Taylor *et al.* 1997) and in Gippsland in Victoria (Loyn 1980, 1985). The beautiful firetail, black-faced cuckoo-shrike and wedge-tailed eagle were also observed in unlogged forest but not in silvicultural regeneration by Green (1977), but in both silvicultural regeneration and mature forest studied by Taylor *et al.* (1997). New Holland honeyeaters were absent from silvicultural regeneration while present in mature forest in one study (Taylor *et al.* 1997), but they exhibited no significant differences in abundance between 17-year-old silvicultural regeneration and mature forest in another (Taylor & Haseler 1995). Similarly, brown thornbills were sometimes adversely affected by silvicultural practices (Dickinson *et al.* 1986, Taylor *et al.* 1997) and sometimes not (Green 1977, Taylor & Haseler 1995).

In spite of the generally deleterious impacts on birds, clearfelling and burning did create habitat for three robin species which foraged in open areas. The favouring of recently logged areas by species which feed on open ground has also been recorded in Victoria (Loyn 1980) and in parts of Tasmania other than those studied here (Green 1977, Dickinson *et al.* 1986, Taylor & Haseler 1995, Taylor *et al.* 1997). However, Coulson & Coulson (1980) regarded this as inadequate compensation for the loss of forest-dwelling birds, because species favouring open areas have already benefited from land clearance for agriculture. Furthermore, this provision of habitat for robins was shortlived, as they were virtually absent from silvicultural regeneration four or more years after burning. Loyn (1980) also found that scarlet and flame robins did not inhabit 6–10-year-old regrowth in Gippsland, and Kavanagh *et al.* (1985) noted that birds typical of open country, which colonised recently logged areas in southeastern NSW, disappeared within two years.

The tendency for dusky and flame robins to frequent areas subjected to burning was also apparent in drier forests in southeastern Tasmania. Both species were more common on burnt logging coupes than on those where logging slash remained (Dickinson *et al.* 1986) and were more abundant after a high intensity fire in woodland than after either a low intensity fire or no fire (Hingston & Black 1998). However, Coulson & Coulson (1980) recorded these two species most frequently in mature dry sclerophyll forest in Tasmania, although they were also present in a recently clearfelled and burnt coupe as well as in six-year-old silvicultural regeneration. Intermediate results obtained by Taylor *et al.* (1997), showed that, although the dusky robin was more common in silvicultural regeneration 0–6 years old than in either older silvicultural regeneration or mature dry sclerophyll forest, flame robins were equally abundant in young silvicultural regeneration and mature forest but less common in older silvicultural regeneration.

The apparent preference of the scarlet robin for the recently burnt coupe which was found during this study contrasts with previous studies in other parts of Tasmania. This species was regularly observed in mature dry sclerophyll forest, but it was never recorded from recently clearfelled coupes or young regrowth during the studies of Green (1977) or Coulson & Coulson (1980). It was also more common in mature dry sclerophyll forest than in recently logged areas investigated by Dickinson *et al.* (1986) and Taylor & Haseler (1995). This difference is most likely to be due to the species inhabiting mature dry sclerophyll forests but not wet sclerophyll forests. This is supported by its absence from wet sclerophyll forest (Green 1977), and the only old-growth forests where it was recorded during the present study being at the drier end of the scale.

The only common species with similar abundances in silvicultural regeneration and old-growth forests was the superb fairy-wren. Other Tasmanian studies have also found this species to be resilient to silvicultural practices (e.g. Green 1977, Dickinson *et al.* 1986). Furthermore, in southeastern NSW this species was more common in areas logged without regeneration burning than in unlogged areas (Kavanagh *et al.* 1985). However, although Taylor & Haseler (1995) found numbers of this species in 17-year-old silvicultural regeneration to be similar to those in mature forest, abundances were significantly lower in three-year-old silvicultural regeneration, suggesting that intense regeneration burns may be disadvantageous to the species. In contrast, Taylor *et al.* (1997) found similar numbers in silvicultural regeneration aged 0–6 years and mature forest, but significantly lower abundances in 6–12-year-old silvicultural regeneration. In the latter case, the low numbers in older silvicultural regeneration may have been the result of only recording birds which were seen together with the dense foliage at eye level (Taylor *et al.* 1997).

CONCLUSIONS

The difference between bird populations in silvicultural regeneration and in other treatments in this study may be even greater than is suggested by the results, due to birds being more easily detected in logged areas (Kavanagh *et al.* 1985, Taylor & Haseler 1995, Taylor *et al.* 1997). The deleterious impact of silvicultural practices on bird populations may also have been underestimated because of the assumption of independence between treatments, which is clearly invalid, because birds are highly vagile. Bird populations in unlogged areas in this study may also have been reduced by logging in nearby areas, as Kavanagh *et al.* (1985) found that some species were less abundant in small unlogged areas than large unlogged areas. Similarly, bird populations in silvicultural regeneration may have been enhanced by the presence of mature forest nearby, as most birds observed in young regrowth by Smith (1984) were transients from nearby mature forest. Furthermore, the number of species in another area of silvicultural regeneration declined after a contiguous area of mature forest was logged (Coulson & Coulson 1980).

This study has demonstrated that bird populations are lower in silvicultural regeneration under 30 years old than in old-growth forests. Hence, forests logged for pulpwood on a rotation length of approximately 30 years are likely to have reduced bird populations throughout. For areas logged on longer rotations for sawlogs, the degree of impact will depend on whether bird populations recover in silvicultural regeneration of more than 30 years of age. However, in Gippsland, fewer birds were found in regrowth aged between 40 and 100 years than in regrowth aged 10–30 years (Loyn 1980). Even if, in southern Tasmania, bird assemblages in older silvicultural regeneration are similar to those in unlogged forests, the overall numbers of birds in the area can still be expected to be dramatically reduced. If forests

are logged on a 60–80 year rotation, at any given time between one-third and one-half of the production area will carry silvicultural regeneration of equivalent age to that studied here and, hence, significantly fewer birds.

Further research should focus on whether species can survive in silvicultural regeneration without nearby mature forest, and whether reserved areas within production forests will be sufficient to maintain viable populations. Studies are also required at other times of the year to fully determine the response of birds to forestry operations, as numerous species are summer migrants to Tasmania, and many other species migrate locally or are nomadic. In the longer term, the questions of how long it takes for bird populations to recover fully from clearfelling and burning of their habitat, and whether bird assemblages recover at the same rate in the second cycle of silvicultural regeneration as in the first, need to be addressed. Future studies would benefit from analyses of the detectability of birds in different habitats, by constructing sightability curves or comparing ratios of birds seen to those heard, and by recording the amounts of time individuals spend in each habitat in addition to the numbers of individuals observed.

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(accepted 28 March 2000)

APPENDIX 1
Numbers of each bird species observed during 15 surveys at each silvicultural regeneration site

Species*	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
SpP	-	-	3	2	2	1	-	-	1	5	1	-	1	3	2
StP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BHH	-	-	-	-	-	-	1	4	2	21	-	10	3	9	11
SBH	-	-	-	-	-	-	3	14	-	20	5	12	8	10	6
YW	-	-	-	-	-	-	-	1	-	-	6	-	-	-	1
BFC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GR	-	-	7	4	1	7	4	7	12	12	11	6	7	20	10
SCC	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
BG	-	-	-	-	-	1	1	1	1	-	-	-	-	-	-
GF	-	-	-	-	-	-	-	5	1	5	1	3	7	6	8
BT	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TT	-	-	14	4	8	8	19	19	6	20	18	21	20	10	9
ST	-	-	-	1	-	1	1	1	4	5	2	9	12	3	3
S	-	-	2	-	11	13	10	12	12	10	13	12	14	12	6
ES	-	-	-	-	-	-	-	-	-	-	-	-	-	-	13
CH	-	3	4	2	3	4	5	17	6	16	6	7	4	19	8
NHH	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
YTH	-	-	-	-	-	1	1	7	2	6	1	1	2	5	5
W	-	-	-	-	-	4	6	3	1	8	4	3	4	5	6
GST	-	-	3	-	-	1	15	13	12	8	9	8	15	12	11
YBC	-	-	-	-	3	-	-	-	1	2	3	2	-	-	-
FF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
FR	3	-	-	-	-	-	1	1	-	-	-	-	-	-	-
PR	-	-	1	2	3	2	2	1	2	7	9	5	3	9	7
SR	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DR	24	1	-	-	-	-	-	-	-	-	-	-	-	-	-
SFW	3	17	1	2	4	2	16	6	2	9	11	-	-	5	-
SW	1	2	3	3	-	6	2	9	3	5	7	6	6	4	5
T	-	-	-	-	-	2	-	-	-	-	-	-	-	1	1
L	-	-	-	-	-	-	1	-	-	-	-	-	-	2	-
GB	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
BC	-	50	-	-	-	1	4	12	38	2	-	3	6	10	3
R	8	-	-	-	-	-	-	-	3	1	-	3	-	4	1
WTE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total birds	46	73	38	20	35	54	92	134	109	162	107	112	112	149	116
Total spp.	6	5	9	8	8	15	17	19	18	18	16	17	15	19	19

* Species codes are given in table 2.

APPENDIX 2
Numbers of each bird species observed during 15 surveys at each non-silvicultural regeneration site

Species*	R1	R2	R3	R4	R5	O1	O2	O3	O4	O5	O6	O7	O8	O9	O10	O11	O12	013
SpP	3	9	5	3	6	3	7	5	3	6	4	6	4	3	5	8	3	2
StP	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-
BHH	5	15	17	18	9	3	15	7	4	5	11	20	13	16	6	7	8	-
SBH	-	21	15	6	4	3	18	7	1	4	16	9	9	12	13	12	19	2
YW	-	1	1	1	-	1	1	-	-	-	-	-	1	-	-	1	-	-
BFC	-	-	-	-	-	-	1	-	-	-	1	-	-	-	-	-	-	-
GR	34	19	35	34	42	13	30	31	29	30	33	42	39	47	36	43	49	74
SCC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BG	-	-	-	2	-	-	-	-	-	-	-	-	1	-	-	-	-	-
GF	3	6	8	10	4	5	7	1	2	11	5	10	6	8	3	9	10	4
BT	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
TT	39	18	13	23	17	22	18	6	29	47	16	42	40	26	19	17	14	19
ST	3	6	7	20	11	2	-	-	7	13	6	2	7	7	8	16	17	21
S	46	47	20	11	4	13	52	32	28	43	34	21	12	8	19	31	15	52
ES	2	4	-	-	1	-	1	2	-	-	16	-	-	5	2	2	-	1
CH	72	23	13	14	4	69	58	58	7	16	28	22	25	4	7	8	11	13
NHH	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
YTH	12	20	18	12	4	9	16	9	12	14	8	10	11	15	12	15	6	2
W	5	5	8	7	6	8	10	4	7	7	10	12	6	8	9	7	6	13
GST	13	28	17	24	13	20	16	7	23	19	17	21	24	17	18	20	20	9
YBC	-	-	2	6	4	5	-	3	2	-	-	3	-	4	1	4	-	-
FF	1	-	-	-	-	2	1	-	-	1	-	-	-	-	-	-	-	-
FR	2	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-
PR	5	6	9	12	12	-	9	5	11	7	11	2	9	5	8	14	22	9
SR	-	-	-	-	-	-	1	-	1	-	-	-	-	-	-	-	-	-
DR	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-
SFW	13	-	1	-	-	-	6	2	10	20	3	3	6	-	-	-	1	4
SW	7	15	16	21	20	10	18	10	19	23	15	20	21	19	20	14	20	12
T	-	-	1	2	4	-	-	-	-	2	2	1	-	-	-	1	1	-
L	-	3	-	1	-	1	-	-	-	-	-	-	1	1	1	1	1	2
GB	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BC	2	91	14	8	6	-	2	-	20	2	5	1	7	67	51	13	4	154
R	-	1	-	1	2	1	3	-	3	1	4	-	1	-	-	4	-	-
WTE	-	-	-	-	-	-	1	-	2	-	-	-	-	-	-	-	-	-
Total birds	267	338	220	236	173	190	291	193	221	271	245	250	244	273	239	247	227	393
Total spp.	18	19	19	21	19	18	22	17	21	19	20	19	21	19	19	21	18	17

* Species codes are given in table 2.

NEW PHREODRILIDAE (ANNELIDA: CLITELLATA) FROM TASMANIAN ESTUARIES

by Adrian M. Pinder and Christer Erséus

(with one text-figure)

PINDER, A.M. & ERSÉUS, C., 2000: (31:xii): New Phreodrilidae (Annelida: Clitellata) from Tasmanian estuaries. *Pap. Proc. R. Soc. Tasm.* 134: 29–33. ISSN 0080–4703. Department of Conservation and Land Management, PO Box 51, Wanneroo, WA, Australia 6946 (AMP); Department of Invertebrate Zoology, Swedish Museum of Natural History, Box 50007, SE-104 05, Stockholm, Sweden (CE).

A new species of Phreodrilidae from Macquarie Harbour, Tasmania is described. *Astacopsidrilus ostiensis* sp. nov. is unique in possessing the combination of long, tightly folded atria, modified spermathecal chaetae and ventral chaetae that are almost simple pointed. These are the first phreodrilids to be recorded from estuarine or intertidal habitats, other than two species collected from beaches, on Subantarctic Campbell Island, for which the habitat data are ambiguous. The existence of other Phreodrilidae from Tasmanian estuaries, of which we do not have sufficient material for description, is noted.

Key Words: Clitellata, Phreodrilidae, estuaries, Tasmania, new species.

INTRODUCTION

In recent decades, hundreds of new oligochaetes in the families Tubificidae and Enchytraeidae have been described from marine and estuarine environments in Australia and elsewhere (e.g. Jamieson 1977, Erséus 1981, 1990a,b, 1993, 1997a,b, Erséus & Jamieson 1981, Coates 1990, Healy & Coates 1997), exceeding the number of species of these families from inland waters. By contrast, of the 45 described species of Phreodrilidae and others awaiting description in the first author's collection, almost all appear to be restricted to inland freshwater habitats such as streams and lakes (Martin & Brinkhurst 1994, Giani *et al.* 1995, Martin & Giani 1995, Pinder & Brinkhurst 1997).

Of the phreodrilids, the only record of *Insulodrilus litoralis* (Michaelsen 1924) is of the type specimens which were collected at Perserverence Harbour, Subantarctic Campbell Island, from under a rock on the beach at ebb-tide. While this may be a marine littoral species there is no information about salinity at the type locality. *Astacopsidrilus campbellianus* (Benham 1909) was also collected on a Campbell Island beach, but near the outlet of a freshwater stream and the species is common in freshwater streams of Macquarie Island, 900 km west of Campbell Island (Marchant & Lillywhite 1994). Finally, the type locality of *Antarctodrilus niger* (Beddard 1894) is given as Port Stanley, Falkland Island, by its original author, but Michaelsen (1900) expanded on this, giving the locality as "zwischen Algen in einem langsam fliessenden Bach" (among algae in a slow flowing brook). All other phreodrilids identified as *A. niger* (or its synonyms) are from inland streams and rivers (Beddard 1894, Goddard & Malan 1913, Brinkhurst 1966, 1982).

The new species and other, unnamed, material described in this paper were collected from brackish reaches of estuaries in Tasmania. These were part of a collection of oligochaetes obtained during an extensive biological study of Tasmanian estuaries (Edgar *et al.* 1998), which was placed at the second author's disposal.

MATERIALS AND METHODS

The material used in this study was collected by Neville Barrett (Tasmanian Aquaculture and Fisheries Institute) and kindly forwarded to us by Graham Edgar (University of Tasmania). The specimens were fixed in formalin, and subsequently transferred to 80% ethyl alcohol. Some worms were stained in alcoholic paracarmine and mounted whole in Canada balsam, a few others were serially sectioned, mounted and stained in Mayer's haematoxylin and eosin. The type specimens of *Astacopsidrilus ostiensis* sp. nov. are deposited in the Queen Victoria Museum (QVM), Launceston, Tasmania, and the Western Australian Museum (WAM).

SYSTEMATICS

Astacopsidrilus Goddard, 1909

Astacopsidrilus Goddard *Proc. Linn. Soc. NSW* 33: 769, figs 1–17 (1909).–Brinkhurst *Can. J. Zool.* 69: 2040 (1991). –Pinder & Brinkhurst *Invert. Tax.* 11: 496 (1997).–Giani *et al. Can. J. Zool.* 73: 2375 (1995) — *Hesperodrilus* Beddard *Trans. R. Soc. Edin.* 36: 273 (1891) (in part).–Michaelsen *Vidensk. Medd. Dan. Naturhist. Foren.* 75: 208 (1924). –Stephenson *THE OLIGOCHAETA*, Oxford University Press: 756 (1930) — *Phreodrilus* (*Astacopsidrilus*) Beddard *Trans. R. Soc. Edin.* 36: 273 (1891).–Brinkhurst *J. Zool.* 147: 381 (1965).

Diagnosis

Plesiopore female ducts (ducts leading to pores on the first segment after the ovaries) leading to pores within ventral spermathecal vestibulae. Spermathecal vestibulae deep and muscular with muscular connections to the dorsal body wall. Well-developed pendant penes present.

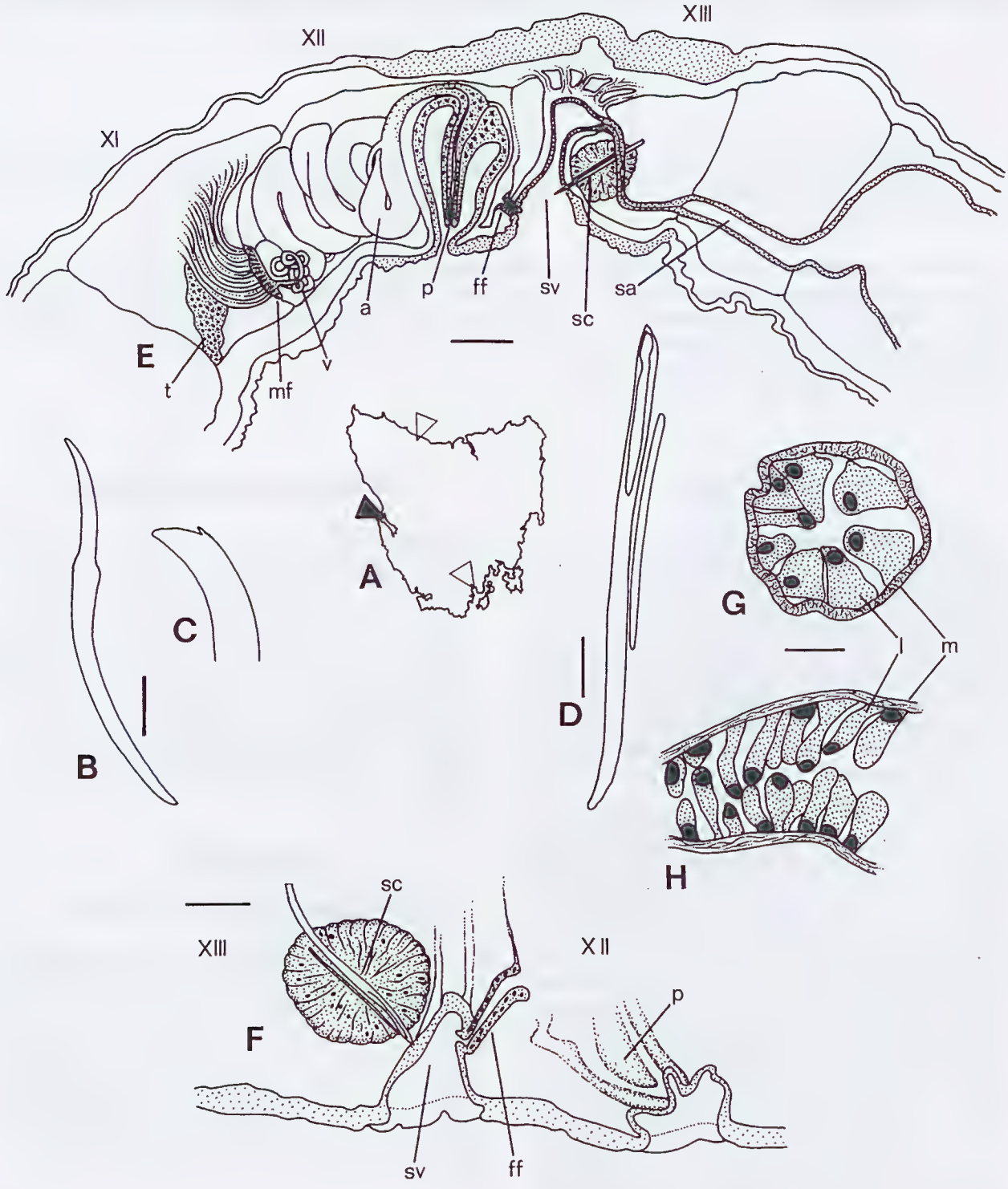

FIG. 1 — Astacopsidrilus ostiensis *sp. nov. (A) Map of Tasmania showing the type locality of* A. ostiensis *(filled arrow head) and location of estuaries with other phreodrilids (open arrow heads); (B) Typical ventral chaeta; (C) Tip of ventral chaeta showing rudimentary upper tooth; (D) Spermathecal chaetae; (E) Longitudinal view of genital segments, reconstructed from sectioned holotype; (F) Ventro-lateral view of genital pores drawn using drawing tube from whole-mounted paratype QVM 14:3866; (G) Transverse section of atrium from holotype; (H) Longitudinal section of atrium from holotype. Legend: a – atrium; ff – female funnel; l – lining tissue; m – muscle; mf – male funnel; p – penis; t – testes; v – vas deferens; sa – spermathecal ampulla; sc – spermathecal chaetae; sv – spermathecal vestibule. Scales: B, D, G and H, bar = 15 µm; E, bar = 100 µm; F, bar = 40 µm.*

Astacopsidrilus ostiensis sp. nov. (fig. 1)

Specimens examined

Holotype: QVM 14:3865. Swan Bay, Macquarie Harbour, west coast of Tasmania, 41°12.384'S 145°16.207'E (fig. 1A), 23 June 1996, longitudinally sectioned specimen on two slides with posterior part mounted separately on a third slide. Paratypes: QVM 14: 3866 to 3877 and WAM V 41-40 to 41-42. Type locality and date, three longitudinally sectioned specimens with posterior parts mounted separately, eight whole-mounted specimens, and several mature and immature ones in alcohol.

Etymology

From the Latin *os* (of the mouth, including river; as in *Ostia*, the harbour of Rome at the mouth of the Tiber), referring to the estuarine type locality.

Description

Length of preserved slide mounted worms up to 11.5 mm, width up to 0.5 mm just anterior to clitellum, body constricted at clitellum. Number of segments 60–75. Clitellum covering posterior half of XII and all of XIII, more developed dorsally than ventrally.

Ventral chaetae two per bundle from segment II, 75–90 µm long, shortest in first few segments, both chaetae of a pair appearing simple pointed (fig. 1B) but many with a rudimentary upper tooth (fig. 1C). Dorsal chaetae from III, each bundle with one or two short (100–150 µm) hairs, each with two support chaetae. Ventral chaetae of XII absent in mature specimens, those of XIII (spermathecal chaetae) two pairs, each pair lying in a large glandular chaetal sac behind corresponding spermathecal vestibule; first chaeta large (110–130 µm), deeply grooved distally, sharply pointed and projecting into vestibulae, second chaetae smaller, thinner and not projecting from sac (fig. 1D–F). Spermathecal chaetae absent in some mature specimens.

Dorsal muscular pharyngeal pad in II–III, with pharyngeal glands attached to either side of septa 3/4 to 5/6. Oesophagus in IV–IX, folded once in each segment and lined with ciliated cells. Gut widening in X, thereafter lining tissue folded and lacking cilia.

All genital pores ventral and paired. Male pores posteriorly on XII in line with ventral chaetae. Spermathecal vestibulae opening anteriorly on XIII in line with male pores, female pores on anterior wall of opening of spermathecal vestibulae (fig. 1E, F). Spermathecal vestibulae with wide openings connected by a shallow transverse depression of body wall.

Testes antero-ventral in XI (fig. 1E), with developing sperm present as far anterior as IV. Ovaries in XII, stringing out into XIII or even XIV, probably due to atria occupying much of XII, with egg sacs present in XIII–XV. Sperm funnels antero-ventral on 11/12 with vasa deferentia highly coiled anteriorly in XII (fig. 1E). Union of atria and vasa deferentia not seen, but in sectioned worms, vas clearly seen near penis sacs so union presumably near where atria narrow before joining the penes. Unciliated atria long and tightly folded, occupying a large proportion of XII, with thin muscle layer, narrow lumen and thick unciliated lining tissue. The latter consisting of tall, flat cells, most of which are not in close contact with neighbouring cells, lending a loose appearance to the tissue (fig. 1G, H), but see remarks below. Penes tall, in muscular sacs that are almost as tall as the segment. Female funnels leading to pores on anterior face of the spermathecal vestibulae, near their wide openings (fig. 1F). Spermathecal vestibulae tall and muscular with muscular attachments to dorso-lateral body wall (fig. 1E). Spermathecal ducts leading from posterior of the slightly bulbous dorsal portion of vestibulae, travelling ventrally, then posteriorly to spermathecal ampullae which cover two or more segments from XIV or XV. Ampullae narrow and elongate anteriorly, becoming bulbous posteriorly. Sperm loose in ampullae, including its narrow anterior portion.

Remarks

This species is placed within *Astacopsidrilus* because of the tall muscular spermathecal vestibulae with female pores located within the openings of these, as per the above diagnosis. *Astacopsidrilus plumaseta* (Brinkhurst & Fulton 1979), also from southeastern Tasmania and *A. beckettae* Pinder & Brinkhurst 1997, from Subantarctic Campbell Island, are the only other *Astacopsidrilus* to have modified spermathecal chaetae. However, the brush-tipped dorsal chaetae of *A. plumaseta* are absent in the new species, while *A. beckettae* possesses more distinctly bifid ventral chaetae, and narrower, less tightly folded atria with more uniform lining tissue, than those of the new species. The cells of the atrial lining tissue of *A. ostiensis* are distinct and appear separated from each other (fig. 1G, H), as in the Tasmanian *A. myothyros* Pinder & Brinkhurst 1997. Although it cannot be ruled out that the appearance of the *A. ostiensis* atrial lining tissue is an artifact of preservation or processing, most other phreodrilids, which have tightly packed atrial cells giving a more homogeneous appearance (Pinder & Brinkhurst 1997: fig. 107) have generally been treated in the same way. Compared to *A. myothyros*, the penes of *A. ostiensis* are more elongate, and the atrial muscle layer is thinner. The chaetae of the two species also differ significantly. The ventral chaetae of *A. myothyros* have the upper tooth larger than the lower anteriorly and are simple-pointed posteriorly.

In the key to Australian phreodrilids of Pinder & Brinkhurst (1997), *A. ostiensis* would key to couplet 17, where it would be separated from either of the options because of the rudimentary upper teeth on anterior ventral chaetae, and the discrete cells projecting into the atrial lumen, rather than atria with a dense layer of atrial lining cells.

The type specimens were collected from fine sand at low-water mark in water with 4.7 ppt salinity. This salinity is unlikely to be greatly exceeded at other times of the year (G. Edgar, pers. comm.).

Other Worms

A specimen collected from the Huon River, near Cradoc, southeastern Tasmania, on 5 November 1997, has chaetae similar to those of *A. ostiensis*, except that the upper teeth of the ventral chaetae are more obvious. The atria of this specimen have more evenly distributed, tightly packed lining tissue than *A. ostiensis*, are less tightly folded and lead, via narrow ejaculatory ducts, to a pair of small sacs which may contain small penes. The spermathecal ducts lead to simple ventral pores, i.e. without vestibulae. This worm was collected at low-water mark in water of 4.3 ppt salinity. Another individual, with similar chaetae but with genitalia that were difficult to observe, was collected at the same site on 16 May 1997 in water of 7.4 ppt.

A specimen from Blythe River, north coast of Tasmania, collected 16 January 1997, has similar chaetae to the Huon

River material; it also has simple ventral spermathecal pores but has larger penes. Details of the atria are not visible from the single whole-mounted specimen. This specimen was collected at low-water mark in water of 14 ppt salinity.

Based on the genitalia, these other phreodrilids appear similar to species currently placed in the genus *Insulodrilus* or *Nesodrilus*, but identifications or descriptions will have to await the examination of further specimens.

DISCUSSION

As mentioned above, tall, muscular spermathecal vestibulae with openings associated with the female pores are considered diagnostic of the genus *Astacopsidrilus* (Pinder & Brinkhurst 1997). *Insulodrilus tanganyikae* (Brinkhurst 1970) also has tall, muscular spermathecal vestibulae, but its female pores are well anterior to these (Brinkhurst 1970: fig. 1A, confirmed by P. Martin, pers. comm.), possibly within the intersegmental furrow or only just behind septum 12/13, although penetration of the septum can be difficult to detect. *Insulodrilus litoralis*, which has small vestibulae, has female pores in a similar position (Michaelsen 1924: fig. 1). Some other *Insulodrilus*, such as *I. nudus* (Brinkhurst & Fulton 1979), have female ducts that are clearly plesioporous and lead to pores located between 12/13 and the openings of the spermathecal vestibulae (Pinder & Brinkhurst 1997: fig. 86), but all of these have vestibulae that are shorter and less muscular. Within *Astacopsidrilus*, some (such as *A. myothyros*) have female pores deep within the spermathecal vestibulae, while others (such as *A. beckettae*) have the female pores just coincident with the vestibulae openings. Thus, there is a continuity in the position of the female pores, such that it sometimes becomes difficult to state whether or not the female pores are separate from, or within, the vestibulae. With the new species, the openings of the vestibulae are so wide and so anterior that it is hard to imagine the female ducts penetrating 12/13 and not appearing to be within the vestibulae. Female pores that are coincident with, or lying within, the vestibulae are probably a result of the extent of development of the latter, which leave little room for separate female pores. *Insulodrilus tanganyikae* is the exception here, although the illustration of this in Brinkhurst (1970) shows the vestibulae to be quite thin-walled ventrally. *I. tanganyikae* possibly belongs within *Astacopsidrilus* because of its tall vestibulae that are clearly very muscular dorsally. This would lead to a lesser emphasis on the position of *Astacopsidrilus* female pores, the location of which would merely be seen as a secondary result of the development of the vestibulae. The highly developed vestibulae would then become the principal synapomorphy uniting the species of *Astacopsidrilus*.

Of the 55 Tasmanian estuary sites sampled by Graham Edgar and Neville Barrett, oligochaetes were identified from only 36, and phreodrilids occurred at only three of these. These three sites had salinities less than half seawater (4.3–14 ppt), whereas many tubificids and enchytraeids were collected at sites with fully marine conditions (salinity about 35 ppt). This, and the similarity of *A. ostiensis* to several of the freshwater Tasmanian *Astacopsidrilus*, suggest that the new phreodrilids are derived from limnic forms and are probably restricted to the low salinity parts of estuaries.

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COMPOSITION, SEASONAL OCCURRENCES AND HABITAT USE OF BIRD ASSEMBLAGES IN WET FORESTS ON THE CENTRAL PLATEAU OF TASMANIA

by Raymond N. Brereton and Robert J. Taylor

(with five tables and four text-figures)

BRERETON, R.N. & TAYLOR, R.J., 2000 (31:xii): Composition, seasonal occurrences and habitat use of bird assemblages in wet forests on the Central Plateau of Tasmania. *Pap. Proc. R. Soc. Tasm.* 134: 35–43. ISSN 0080–4703. Nature Conservation Branch, Department of Primary Industries, Water and Environment, Hobart, Tasmania, Australia 7000 (RNM); and Forestry Tasmania, 79 Melville Street, Hobart, Tasmania, Australia 7000 (RJT).

Bird communities in montane wet forest at three sites (altitudes 700, 750 and 880 m) on the Central Plateau of Tasmania were surveyed over a 12-month period between December 1991 and November 1992. Monthly transect counts were carried out at each site. Snowfalls are common at all three sites during winter and snow can remain at the highest site for several weeks. Bird communities at the study sites showed significant differences in densities and seasonal patterns even though species composition was similar. These differences were influenced by the variation in habitats and the environments at the sites. Butlers Road, the lowest site with the mildest winters and greatest proportion of drier habitat, had the highest bird densities, while D'Arcys Bluff, at the highest altitude, had the lowest. The degree of seasonal changes of birds was similar to mainland montane wet forests, with over half the species moving either locally or to the mainland. However, there was variation in seasonal occurrences between the study sites, with proportionally more species moving from the highest site during the winter. Within the study sites, the wet forest habitats with a diverse shrub and/or fern understorey supported higher bird populations than did mixed forest and damp forest. Species richness is lower at these sites compared with equivalent montane forests on mainland southeastern Australia.

Key Words: bird communities, montane wet forest, Tasmania, bird density, species diversity.

INTRODUCTION

There have been a number of studies conducted in southeastern Australia describing the composition, seasonal changes and habitat use in bird communities in a range of forest types, including temperate rainforest (Thomas 1980), wet forests (Lamm & Wilson 1966, Pattemore 1980, Smith 1984, Loyn 1985a, 1993, Robinson 1991); dry forests and woodlands (Pattemore 1980, Recher *et al.* 1983, Recher & Holmes 1985, Dickinson *et al.* 1986, Cale 1994, Mac Nally 1995, 1996, Taylor & Haseler 1995). However, there has been only one major study of the bird communities of wet forest in Tasmania that collected information over all seasons, that carried out by Pattemore (1980) in the Florentine Valley. Of the studies of birds in southeastern Australia, few have been undertaken on the bird communities in montane forests, where the winters are exceptionally harsh and snow can be continually present for weeks. Gall & Longmore (1978) and Osborne & Green (1992) reported on studies in the Snowy Mountains. However, these were centred on alpine and subalpine communities. Lamm & Wilson (1966) carried out a survey of the bird communities in montane wet forest in the Brindabella Range in the Australian Capital Territory and Thomas (1987) and Ratkowsky & Ratkowsky (1976, 1978) reported on bird communities in montane wet forest on Mount Wellington in Tasmania.

This paper documents bird communities at three sites in montane *Eucalyptus delegatensis* wet forest on the Central Plateau of Tasmania. The patterns of seasonal occurrences and use of habitats at the three sites are compared and discussed in relation to other studies in forests in similar environments. This study was undertaken as part of the pre-logging data collection for a project investigating the value for fauna of retained strips in production forests.

STUDY AREAS

Three areas on the Central Plateau of Tasmania were sampled. These were D'Arcys Bluff (AMG 4420 53291, elevation 880 m, northwestern aspect), Hornes Dam (AMG 4475 53196, 750 m, southerly aspect) and Butlers Road (AMG 4473 53164, 700 m, southerly aspect). Jurassic dolerite underlies all three areas and forms a variably dense surface cover of Quaternary talus. Temperatures at the nearby settlement of Butlers Gorge (666 m) range from February mean daily minima and maxima of 6.2°C and 18.7°C respectively, to July mean daily minima and maxima of –0.4°C and 6.9°C respectively. Snowfalls are common in winter, and at D'Arcys Bluff snow can lie on the ground for several weeks. Annual precipitation at Butlers Gorge, including snow, averages c. 1684 mm, with a winter maximum and summer minimum.

Small areas of cool temperate rainforest dominated by *Nothofagus cunninghamii* are present at Butlers Road. Rainforest also occurs at Hornes Dam with *Leptospermum lanigerum* as a co-dominant. Vegetation at all three study areas is dominated by tall, open sclerophyll forest with c. 150–200 year old *Eucalyptus delegatensis*. The sclerophyll forest can be broadly subdivided on the basis of the affinities of the understorey species. Mixed forest has an understorey dominated by rainforest species. Wet sclerophyll forest has an understorey dominated by mesophytic (soft-leafed shrubs) and damp sclerophyll forest has an understorey with a mixture of species characteristic of both wet and dry forests. Shrub and ground cover varies within sites depending on canopy cover, dryness and surface rock abundance. The ground in wetter spots is bare under denser tree canopies, while the tree-fern *Dicksonia antarctica* is common in wetter, more open areas. On drier sites the shrub layer consists of a mixture of species including *Cyathodes parvifolia, Pultenaea juniperina, Telopea truncata,*

Phebalium squameum, regrowth *N. cunninghamii* and *Tasmannia lanceolata.* On the more rocky sites dominant species include *Bedfordia salicina, Notelaea ligustrina, P. squameum, Acacia verniciflua* and *Pomaderris apetala.*

A vegetation survey of the study areas (F. Duncan & M. Brown, pers. comm.) utilised classification techniques (TWINSPAN, Hill 1979) on cover-abundance floristic data to identify communities. Twelve communities were identified. Two of these are rainforest communities. The remaining ten communities contained *E. delegatensis* as the dominant tree. The twelve communities were combined into four habitat types by grouping communities with a similar structure and floristic affinities (table 1).

METHODS

A line transect method was used to survey birds. Two transects were located at Butlers Road, four transects at Hornes Dam and three transects at D'Arcys Bluff. Length of individual transects varied between 0.337 km and 0.484 km. The transects were split into sections of different lengths (piece-wise linear design — Burnham *et al.* 1980) to enable the sampling of different habitats in non-homogenous terrain. Transect length in each habitat is given in table 2.

Transects were surveyed (by RB) during a ten-day visit to the study area during the middle of each month from December 1991 to November 1992. Transects at Butlers Road were surveyed once per monthly visit, apart from June when they were surveyed twice. The Hornes Dam and D'Arcys Bluff sites were surveyed twice per month with the following exceptions: due to poor weather conditions at Hornes Dam in December and January, two of the four transects were only surveyed once; at D'Arcys Bluff in December, one of the three transects was only sampled once; none of the transects at D'Arcys Bluff could be surveyed in June as heavy snowfalls prevented access to the site. Transects were traversed during the morning, generally during the first four hours after sunrise. Surveys sometimes extended beyond this time, when poor weather led to a delayed start.

The transects were traversed at a steady walking pace. All birds seen were recorded regardless of distance from the line. Birds that were heard and not located and birds flying overhead were noted but not included in the count. For each bird detected, a sighting distance and angle (between the line of travel and the line of sight to the object) were recorded.

Observations of birds were assigned to one of four height classes based on the structure of the vegetation and were decided prior to the commencement of the study. The height classes used were: canopy, 20+ m (*E. delegatensis* crowns); mid layer, 5–20 m (tall shrubs, secondary trees); lower layer, 1–5 m (shrubs); and ground layer, 0–1 m (ground surface, fallen timber, low shrubs).

Species were assigned to classes based on the height class in which they were most frequently observed over all seasons. These are dwelling height classes as opposed to foraging classes, because they are not based on observations of foraging activity. However, for most species they equate to the height class in which most foraging is undertaken. The exceptions are species such as the robins and the fan-tailed cuckoo, which pounce on invertebrate prey on the ground from low perches, and the forest raven, which forages across a range of height classes. The substrate on which a bird was perched when first detected was also recorded.

TABLE 1
The four habitats, their affiliation with current Tasmanian wet eucalypt forest classification and their occurrence in the study areas

Habitat types*	Mixed forest (MF)	Mixed/wet forest with dense ground ferns (WFf)	Mixed/wet forest with a shrubby understorey (WFs)	Damp forest with a shrubby understorey on rocky ground (DF)
Description	Cool temperate rainforest and mixed forest communities and is characterised by a dense secondary tree layer.	Intermediate between a mixed and wet forest with *N. cunninghamii* usually sparse or absent as a secondary tree. Dry sclerophyll shrubs and/or wet ferns are common.	An open to dosed tall shrub layer is present.	Mixture of dry and wet forest shrubs. Present on areas with a high cover of rocks. Shrub layer varied from open to closed, particularly at Homes Dam. *Lomatia tinctoria* was present in this community at Butlers Road.
Affiliation with Kirkpatrick *et al.* (1988) classification	DEL 1000, DEL 1001 and DEL 1100 mixed forest communities	DEL 0111 mixed/wet forest community	DEL 1011 and DEL 0111 mixed/wet forest communities	DEL 0010 and DEL 0011 wet forest communities
Occurrence†				
Butlers Road	+	+	absent	+
Hornes Dam	+	+	absent	+
D'Arcys Bluff	+	limited	+	absent

* The habitat types are listed in their probable order along an available moisture gradient from wettest to driest.
† + indicates that the habitat type occurs at that area.

TABLE 2
Transect length in each habitat at the three study sites

Site	Habitat				Total
	MF	WFf	WFs	DF	
Length of transects (km)					
BR	0.486	0.472	-	0.209	1.167
HD	1.174	0.652	-	0.426	2.252
DB	0.920	0.039	0.828	-	1.787
Total length (km) of transect sampled over the whole of the study					
BR	6.32	6.14	-	2.71	15.17
HD	26.54	14.83	-	9.88	51.25
DB	19.90	0.854	17.91	-	38.67

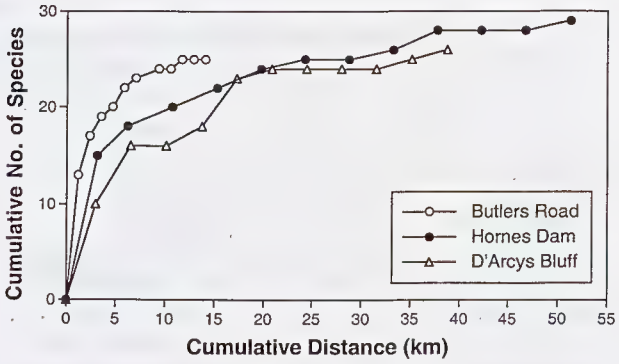

FIG. 1 — Number of species sighted as a function of the length of transect sampled.

Substrates included the ground (litter), rocks , fallen timber (trunks and branches >100 mm), stags (dead standing timber) and plant species. Incidental observations of foraging behaviour were also recorded.

Species were assigned a residency status based on their seasonal pattern of occurrence (from both sightings and calls) in the study area. Four categories were recognised:

Resident — species was present all year

Summer visitor — species was only present in the summer months or present at other times in very low numbers relative to the size of the breeding population

Winter visitor — species was present only in the winter months or present at other times in very low numbers relative to the size of the non-breeding population

Itinerant — species was present in all seasons but not in all months. The species may or may not breed in the study area.

TRANSECT, a computer program which analyses line transect data (Laake *et al.* 1980, Burnham *et al.* 1980), was used to calculate total densities of birds. The estimates of density were carried out on truncated grouped data. The greatest observed distance formed the truncation point, except in some cases where extreme observations (outliers) were excluded from the analysis, as recommended by Laake *et al.* (1980). The significance of differences in density between sites and in different habitats was assessed by comparing the difference in the population means with the 95% confidence interval for this difference.

Sorenson's index (Barbour *et al.* 1980) was used to compare the similarity of the species composition at the three sites.

RESULTS

The numbers of species observed (table 3) and the rate of detection (fig. 1) were greatest at Butlers Road and lowest at D'Arcys Bluff. Densities of birds were significantly higher at Butlers Road than at D'Arcys Bluff ($p < 0.05$, table 3), with densities at Hornes Dam not significantly different from the other two sites. Species composition (based on relative abundances within each site) was more similar at Butlers Road and Hornes Dam than at D'Arcys Bluff (Sorenson's indices: Butlers Road and Hornes Dam = 0.84; Hornes Dam and D'Arcys Bluff = 0.74; Butlers Road and D'Arcys Bluff = 0.67).

Seasonality

Of the 32 species recorded during the study, 38% were resident, 28% were summer visitors, 19% were winter visitors and 15% were considered to be itinerant to the area (table 3). Numbers of species tended to be lowest during winter and highest in late spring and early autumn (fig. 2).

The general seasonal pattern of sightings for resident species was low numbers in winter, an increase in early spring, followed by a decline in late spring–summer and an increase in sightings again in summer–autumn (e.g. Tasmanian scrubwren, fig. 3). However, two resident species, both honeyeaters, the strong-billed and the black-headed honeyeater, were present in low numbers during summer, not recorded in some months post-breeding and showed a peak during winter (fig. 3).

The summer visitors were either species which breed in Tasmania and overwinter on the mainland (e.g. fan-tailed cuckoo, grey fantail (fig. 3), striated pardalote) or mainly local migrants which moved in from lower altitudes (e.g. flame robin, crescent honeyeater). The three mainland migrants, the black-faced cuckoo-shrike, grey fantail and silvereye, arrived in October and departed in April and May.

The winter visitors were all local migrants, although the brown thornbill is probably resident in low numbers at Butlers Road (fig. 3). The spotted pardalote was seen on only one occasion in spring at Butlers Road. The superb fairy-wren, grey butcherbird and grey currawong are casual winter visitors, only seen in low numbers and not at all sites. The superb fairy-wren was observed only at Butlers Road and not during transect counts.

The black currawong was the only itinerant species recorded breeding at any of the sites. A nesting bird and juveniles were observed at D'Arcys Bluff and juveniles were also observed at Hornes Dam. The other four itinerant species were sighted on transects at some time during the breeding season and, thus, possibly also breed at the sites (fig. 3). All of the itinerant species are medium to large-sized birds which range widely in search of suitable feeding and breeding areas. Thus, they may be resident in the area but only occasionally be present on transects. Sightings of the black currawong and the yellow wattlebird peaked in the post-breeding period. The increase in numbers in this period was in part due to the presence of post-breeding flocks. In particular, the black currawong was more often

TABLE 3
Relative abundance of each species and total density of birds at three wet forest sites on the Central Plateau of Tasmania

Species		Abundance‡		
		Butlers Road	Hornes Dam	D'Arcys Bluff
Resident				
Brush bronzewing	*Phaps elegans*	+	0.04 (1)	–
*Green rosella	*Platycercus caledonicus*	7.1 (9)	3.2 (11)	6.5 (7)
†Superb lyrebird	*Menura novaehollandiae*	+	0.04 (1)	0.1 (1)
White's thrush	*Zoothera dauma*	0.1 (1)	0.2 (4)	0.3 (3)
Pink robin	*Petroica rodinogaster*	0.7 (5)	1.2 (8)	3.4 (10)
Olive whistler	*Pachycephala olivacea*	0.4 (4)	0.4 (8)	0.1 (1)
Grey shrike-thrush	*Colluricincla harmonica*	2.2 (11)	2.2 (12)	0.4 (5)
*Tasmanian scrubwren	*Sericornis frontalis*	15.8 (12)	18.9 (12)	19.4 (11)
*Scrubtit	*Sericornis magnus*	2.9 (9)	4.9 (12)	3.8 (12)
*Tasmanian thornbill	*Acanthiza ewingii*	18.2 (12)	17.1 (12)	31.5 (11)
*Strong-billed honeyeater	*Melithreptus validirostris*	23.4 (11)	16.9 (11)	7.6 (6)
*Black-headed honeyeater	*Melithreptus affinis*	10.6 (10)	10.3 (11)	2.2 (4)
Summer visitor				
Fan-tailed cuckoo	*Cuculus pyrrhophanus*	+	0.04 (1)	+
Shining bronze-cuckoo	*Chrysococcyx lucidus*	0.2 (1)	+	0.6 (5)
Black-faced cuckoo-shrike	*Coracina novaehollandiae*	0.3 (2)	0.4 (5)	1.0 (3)
Flame robin	*Petroica phoenicea*	0.5 (3)	0.2 (3)	0.2 (2)
Grey fantail	*Rhipidura fuliginosa*	2.7 (6)	1.9 (7)	1.0 (6)
Crescent honeyeater	*Phylidonyris pyrrhoptera*	5.0 (6)	5.0 (7)	3.5 (7)
Eastern spinebill	*Acanthorhyncus tenuirostris*	+	0.1 (2)	0.6 (5)
Striated pardalote	*Pardalotus striatus*	0.7 (4)	1.0 (5)	3.0 (6)
Silvereye	*Zosterops lateralis*	2.5 (6)	4.0 (5)	3.1 (7)
Winter visitor				
Superb fairy-wren	*Malurus cyaneus*	+	–	–
Brown thornbill	*Acanthiza pusila*	2.6 (9)	0.6 (4)	1.1 (4)
*Yellow-throated honeyeater	*Lichenostomus flavicollis*	0.7 (6)	0.4 (4)	0.6 (3)
Spotted pardalote	*Pardalotus punctatus*	0.5 (2)	0.04 (1)	0.3 (1)
Grey butcherbird	*Cracticus torquatus*	0.1 (1)	–	–
Grey currawong	*Strepera versicolor*	–	0.1 (1)	–
Itinerant				
Yellow-tailed black-cockatoo	*Calyptorhynchus funerus*	+	0.1 (1)	0.5 (1)
Golden whistler	*Pachycephala pectoralis*	0.5 (4)	0.04 (1)	0.2 (1)
*Yellow wattlebird	*Anthochaera paradoxa*	1.5 (5)	1.9 (8)	0.8 (4)
*Black currawong	*Strepera fuliginosa*	0.6 (4)	8.5 (10)	8.2 (7)
Forest raven	*Corvus tasmanicus*	0.5 (2)	0.3 (5)	+
Density of birds (no./ha)		17.1±3.0	11.5±1.6	9.3±2.5
No. of individuals		1038	2463	1140
No. of species on transects§		29	30	28
No. of species at site		*32*	*30*	*30*

* Species endemic to Tasmania.
† Species introduced from mainland Australia.
‡ Percentage of total number of birds at each site. Number of months a species was observed on the transects is shown in brackets.
\+ Species present at site but not recorded on transect.
– Species not recorded at site.
§ Includes birds seen and heard.

observed in flocks outside of the breeding season. Flocks of 30–40 birds were not uncommon and one flock of 400 birds was observed passing through D'Arcys Bluff in winter.

The pattern of seasonal changes in densities of birds differed between the sites (fig. 4). At D'Arcys Bluff densities were greatest during the autumn months, whereas at Hornes Dam highest densities were recorded during summer. Bird densities at Butlers Road were more uniform over the year, apart from two months of the year when densities were markedly different, being high in February and low in October.

Use of Height Classes by Species

The percentage of species in each height class use group was: canopy 37%, mid layer 30%, lower layer 20% and ground 13% (table 4). Birds which were recorded mostly in the lower layer, apart from the yellow-tailed black-cockatoo, also used the ground layer and the mid layer with little or no use of the canopy. Of the species classified as mid layer species, the brown thornbill, grey fantail and silvereye also had a high use of the lower layer and the grey shrike-thrush had a high use of the canopy. The crescent honeyeater had

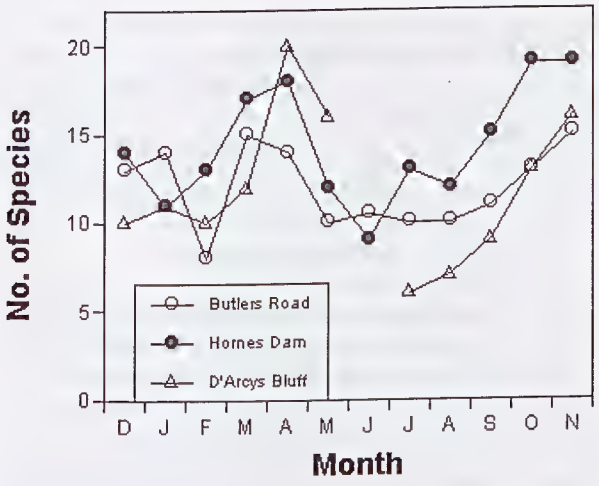

FIG. 2 — Numbers of species sighted each month for the three study areas on the Central Plateau of Tasmania.

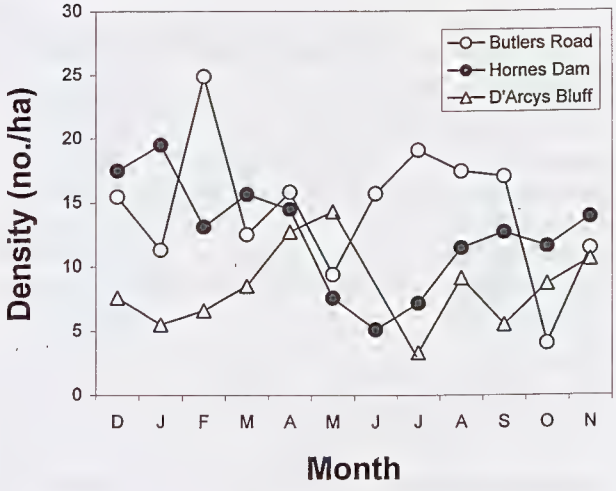

FIG. 4 — Density of birds each month at the three study areas on the Central Plateau of Tasmania.

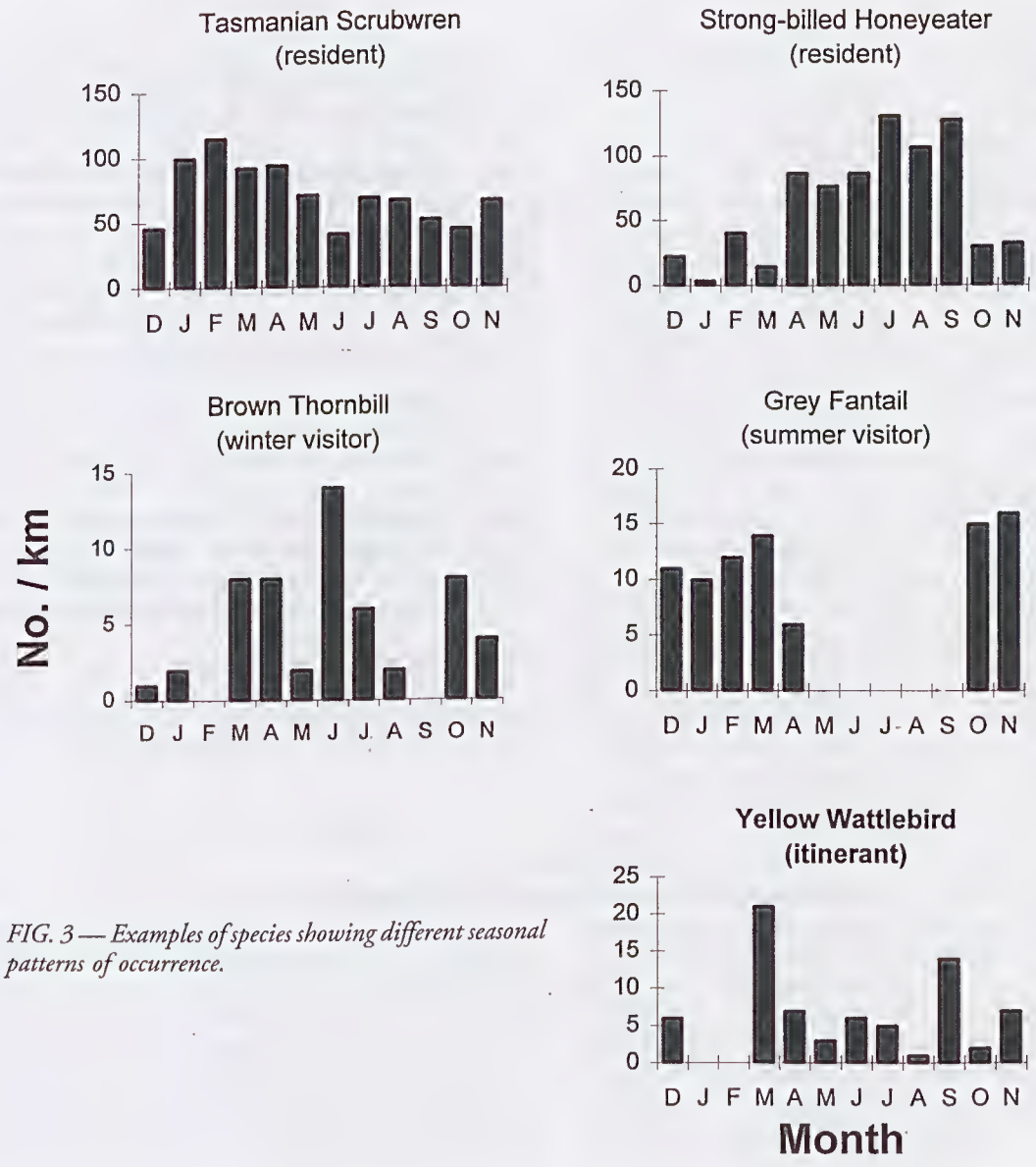

FIG. 3 — Examples of species showing different seasonal patterns of occurrence.

TABLE 4
Occurrence of species (% of observations) in height classes across all study sites

Species	Ground	Low	Mid	Canopy	n	Foraging strategy
Canopy						
Green rosella	0	14	35	51	229	taking seed and probing under bark on trunks and branches for invertebrates
Spotted pardalote	0	0	0	100	5	gleaning invertebrates from foliage
Striated pardalote	0	0	12	88	60	gleaning invertebrates from foliage
Yellow wattlebird	0	0	19	81	72	probing in and under bark on trunks and branches for plant and insect exudates and invertebrates
Yellow-throated honeyeater	0	16	28	56	25	probing in and under bark on trunks and branches for plant and insect exudates and invertebrates
Strong-billed honeyeater	0	1	27	72	762	probing in and under bark on trunks and branches for plant and insect exudates and invertebrates
Black-headed honeyeater	0	3	20	77	381	probing in and under bark on trunks and branches for plant and insect exudates and invertebrates
Flame Robin	17	24	17	42	12	pouncing on invertebrates on the ground
Golden whistler	0	12	38	50	8	snatching invertebrates from foliage and branches
Black-faced cuckoo-shrike	0	0	0	100	28	snatching invertebrates from foliage and branches
Forest raven	0	0	19	81	16	taking invertebrates and fruits from all layers and carrion from ground
Mid layer						
Fan-tailed cuckoo	0	0	100	0	1	pouncing on invertebrates on the ground
Shining bronze-cuckoo	0	22	56	22	9	snatching invertebrates from foliage and branches
Crescent honeyeater	1	16	58	25	210	probing in and under bark on trunks and branches for plant and insect exudates and invertebrates also taking nectar
Brown thornbill	7	18	71	4	55	gleaning invertebrates from foliage, branches and trunks
Grey shrike-thrush	4	10	52	35	83	probing in and under bark on trunks and branches for invertebrates
Grey fantail	1	35	52	12	84	hawking for insects
Grey currawong	0	0	100	0	2	taking invertebrates and fruits from all layers
Black currawong	12	17	56	15	310	taking invertebrates and fruits from all layers
Silvereye	6	19	69	6	171	fruit, nectar and invertebrates from shrubs and trees
Lower layer						
Yellow-tailed black cockatoo	0	44	22	33	9	taking seeds, probing for wood boring insect larvae and other invertebrates
Scrubtit	37	51	7	5	217	probing for invertebrates on trunks, branches and the ground
Tasmanian thornbill	9	48	40	2	983	gleaning invertebrates from foliage and branches
Eastern spinebill	11	67	22	0	9	taking nectar form the flowers of shrubs
Pink robin	20	53	25	2	81	pouncing on invertebrates on the ground
Olive whistler	13	63	25	0	16	snatching invertebrates from foliage and branches
Ground layer						
Brush bronzewing	100	0	0	0	1	taking seeds from the ground
Superb lyrebird	100	0	0	0	2	probing in litter for invertebrates
Tasmanian scrubwren	82	17	0	0	856	gleaning invertebrates from the ground
Bassian thrush	90	0	10	0	10	probing in litter for invertebrates

TABLE 5
Density of birds* in each habitat at the three study sites

Site	Habitat			
	MF	WFf	WFs	DF
BR	12.3 ± 1.0	20.9 ± 1.3	-	20.2 ± 1.8
HD	10.1 ± 0.4	16.8 ± 0.8	-	10.7 ± 0.7
DB	4.3 ± 0.3	14.1 ± 1.0	14.6 ± 0.8	-

* No./ha ± standard error.

a high use of both the lower layer and the canopy. The black currawong was observed in all height classes. Species which occurred predominantly in the canopy, apart from the black-faced cuckoo-shrike, were also commonly observed in the mid layer with the green rosella and yellow-throated honeyeater also making use of the lower layer.

Habitat Use

At all sites, the densities of birds in wet forest with ferns (WFf) were either greater than other habitats or equivalent to one of the other habitats (table 5). Densities of birds were also lowest at all three sites in the same habitat, the wettest habitat mixed forest (MF), although at Hornes Dam densities were not significantly different from those in damp forest (DF). For each of the habitats there was a decline in density with altitude (i.e. Butlers Road > Hornes Dam > Darcys Bluff).

DISCUSSION

Species Richness

The number of species recorded during the study (32) is similar to that recorded in the three other studies of wet forest bird communities in Tasmania (Ratkowsky & Ratkowsky 1976 — 30 species in *E. delegatensis* forest at 600–800m; Pattemore 1980 — 32 species in *E. regnans* mixed forest at 400–500 m; and Thomas 1986 — 36 species in *E. obliqua* mixed forest at 600 m). In a study of bird assemblages in montane dry forest, Taylor & Haselar (1995) recorded 39 species of birds. This is consistent with other studies in Tasmania, which have shown that dry forests contain a greater number of bird species (Dickinson *et al.* 1986 — 49 species; Taylor *et al.* 1997 — 57 species) than wet forests. This contrasts with studies on the mainland, which have shown that wet eucalypt forests host more abundant and diverse bird communities than dry eucalypt forests (Loyn 1985b, 1993, Recher *et al.* 1985, 1991a, b).

Studies in montane wet forest on mainland southeastern Australia have recorded greater numbers of species than was recorded in this study (46 species — Robinson 1991; 65 species — Loyn 1985a; 63 species — Lamm & Wilson 1966; 61 species — Osborne & Green 1992). Like most islands, Tasmania has fewer bird species than the adjoining mainland, and consequently the avifauna of its forests is less diverse than similar forest on the mainland (Ridpath & Moreau 1966, Thomas 1974).

Seasonal Occurrences

There was considerable seasonal variation in the bird communities at the study sites. Over half of the bird species in the study area move away, either locally or to the mainland, at sometime during the year, and the resident species also displayed seasonal fluctuations in numbers. Similar seasonal changes have been documented in forests in southeastern Australia. Recher *et al.* (1983) observed that about half of the species at their study site in montane woodland in the Southern Tablelands of New South Wales were absent during the winter. In a study of birds in montane wet forest in the Brindabella Range in the Australian Capital Territory, 70% of species left the study site at some time during the year (Lamm & Wilson 1966). Large-scale seasonal changes in species composition have also been recorded in other forest bird communities in southeastern Australia (Robinson 1991, Loyn 1985a, 1993, Mac Nally 1995). The same degree of seasonal variation in bird communities as found in this study has also been recorded in lowland dry sclerophyll forest (250 m a.s.l.) in southeastern Tasmania, where about half the species moved away from the study area at some time (Thomas 1986).

The pattern of changes in species richness over the year is similar to that observed by Recher *et al.* (1983) in montane forest in mainland southeastern Australia. This response to seasonal changes is primarily due to changes in the availability and abundance of insects and the flowering and fruiting of plants (Recher *et al.* 1983, 1991b, Recher & Holmes 1985, Ford 1989).

Despite winter being the harshest season of the year, some species were only regularly observed at this time (e.g. the brown thornbill and yellow-throated honeyeater). These two species did occur in adjacent forests, and a small number of brown thornbills were recorded on occasions in summer at Butlers Road. It appears that during winter these species moved into the study sites as part of a pattern for species to move over larger areas in search of food.

The strong-billed honeyeater and black-headed honeyeater commonly formed mixed feeding flocks in the winter. Other species, such as the grey shrike-thrush, Tasmanian thornbill, crescent honeyeater and yellow-throated honeyeater occurred in these flocks on occasions. An influx of honeyeaters in the winter has been recorded in other montane forests in southeastern Australia (Robinson 1991, Loyn 1993, Recher & Holmes 1985). These mixed feeding flocks foraged mainly under the loose bark shed by the upper trunk and branches of *E. delegatensis*. Bark is shed by eucalypts during late autumn and winter and provides a rich foraging substrate for birds (Recher *et al.* 1983, Turnbull & Madden 1986). Manna and honeydew, both sugar-rich carbohydrate are abundant under loose and peeling bark, which also provides shelter for invertebrates over the winter months.

The number of species was at its highest in spring, when the summer migrants arrived back in the study area. Bird abundance also increased in spring. Shrubs such as *Prostanthera lasianthos* and *Pittosporum bicolor* were flowering at this time and provided a foraging resource for nectivores such as the eastern spinebill. This species moves in from lower altitudes to take advantage of this resource.

The summer decline in species diversity and abundance at the study area is most likely related to the behaviour of birds during the breeding season. In spring, when the summer migrants first arrive, detection of birds is facilitated by their involvement in territorial and mate selection behaviour, resulting in high counts. When birds have formed territories and are nesting it is likely that fewer individuals and fewer species will be detected along transects. After egg laying, birds are less conspicuous, and this probably also contributed to lower counts. However, there was variation between sites. Thus, in February Butlers Gorge had the lowest number of species and the greatest abundance of individuals. This variation in numbers of birds during late spring and summer was also recorded by Recher *et al.* (1983).

The post-breeding increase in numbers of species, and to some degree bird abundance, was probably due to the presence of fledged birds appearing on the transects and was correlated with an increase in the number of flocks observed during the summer–autumn period. Passage migrants (e.g. black-faced cuckoo-shrike) and birds dispersing from other habitats (e.g. brown thornbill, yellow-throated honeyeater) began to appear at the study sites at this time of the year.

D'Arcys Bluff was characterised by greater environmental extremes, with colder winters and heavier and more frequent snowfalls than the two other sites. The seasonal movement of birds in areas with regular winter snowfalls has been related to the reduced availability of food caused by cold weather and shortened day length and the physiological demands of cold weather (Osborne & Green 1992). Proportionally more species left D'Arcys Bluff during winter and moved back into the site during the breeding season compared to the other two sites. The difference between the minimum and maximum numbers of species per month seen on transects was 14 at D'Arcys Bluff compared with ten at Hornes Dam and seven at Butlers Road. This contrasted with variation in densities with the difference between the highest and lowest monthly density being 20.8/ha at Butlers Road, 14.4 at Hornes Dam and 10.9 at D'Arcys Bluff. Thus, although densities were lower at D'Arcys Bluff they were less variable than at the lower altitude sites. This may be due to smaller numbers of summer migrants moving into this highest altitude site but greater numbers of species leaving the site to avoid the harsher winter conditions.

Use of Height Classes

The use of height classes by species at the site is similar to that found for the same species in montane forests on the mainland (Recher & Holmes 1985) with two exceptions, the brown thornbill and the grey shrike-thrush. In forests on the mainland, the brown thornbill is found mostly in shrubs in the lower layer, where it mostly forages for invertebrates in the foliage (Recher *et al.* 1985, Loyn 1985). On the Central Plateau, the Tasmanian thornbill occupies this niche, being a wet forest species which gleans invertebrates from the foliage of shrubs and understorey trees. In contrast, the brown thornbill is mostly found in the midlayer, where it was often observed gleaning for invertebrates on the trunks of trees. The brown thornbill is predominately a winter visitor from surrounding drier forests and may be exploiting a substrate (the trunks of trees) in a height class which is little used at that time of the year. The brown thornbill was present in small numbers at Butlers Road through the summer; this site had a greater area of drier forest.

The grey shrike-thrush predominantly inhabits the ground and shrub layers on the mainland, where it takes invertebrates mainly from the ground and, to a lesser extent, from branches and loose bark (Recher *et al.* 1985). On the Central Plateau, this species was more often observed in upper layers, where it foraged on bark on the trunks and branches of trees. The extensive use of bark substrates by the brown thornbill and grey shrike-thrush has also been recorded by Cale (1994) in dry forests in northeastern Tasmania and by Keast (1968), who suggested it was due to the absence of the specialist bark foragers, the treecreepers (Climacteridae) and varied sittella *Daphoenositta chrysoptera*, from Tasmania.

There was a greater proportion of species classified as canopy species (37%) and a lower proportion classified as ground species (13%) compared with the study of Recher & Holmes (1985) for montane forest in southeastern Australia (12% and 32% respectively). These differences are probably related to the differences in forest structure, with Recher & Holmes (1985) undertaking their study in regrowth with a much reduced canopy height (17–22 m) compared with our sites (50–70 m).

CONCLUSION

This study supports the findings of Mac Nally (1995, 1996) on the variability of bird communities. Thus it appears that bird assemblages of Tasmania, a large island, are as changeable as are continental bird communities. However, despite this changeability, broad-scale differences in the bird communities at these three study sites on the Central Plateau appeared to be related to local environmental changes over a relatively short altitudinal gradient.

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RECONNAISSANCE SURVEY OF A GLAUCOUS EUCALYPT NEAR LOUISA BAY, SOUTHWESTERN TASMANIA

by Kristen J. Williams and Jon B. Marsden-Smedley

(with three tables, four text-figures, three plates and three appendices)

Williams, K.J. & Marsden-Smedley, J.B., 2000 (31:xii): Reconnaissance survey of a glaucous eucalypt near Louisa Bay, southwestern Tasmania. *Pap. Proc. R. Soc. Tasm.* 134: 45–54. ISSN 0080–4703. Forest Ecosystem Research and Assessment, Queensland Department of Natural Resources, 80 Meiers Road, Indooroopilly, Queensland, Australia 4068, formerly School of Plant Science, University of Tasmania (KJW); Fire Management Section, Parks and Wildlife Service, Department of Primary Industries, Water and Environment, GPO Box 44A, Hobart, Tasmania, Australia 7001 (JBM-S).

Stands of a glaucous eucalypt in the vicinity of Louisa Bay, southwestern Tasmania, which has affinities to *Eucalyptus tenuiramis* (Series *Piperitae*), were surveyed in order to determine their taxonomic status and record aspects of their population ecology. Two main populations were observed in scattered stands among predominantly moorland vegetation at the Red Point Hills and Louisa Plains. One stand from each population was accessed for detailed study. Contiguous plots located along transects across the copses were used to record changes in population status, floristics and site conditions. Individuals of the glaucous eucalypt were small in stature and frequently mallee-form near the moorland boundary, but were taller (10–12 m) and straight with single, slender main stems toward the centre of the copse. The Red Point Hills stand comprised a larger number of smaller individuals than the Louisa Plains stand and had been subject to at least three fires in the last 65 years, whereas only one fire had occurred on the Louisa Plains in the same period. These observations have implications for fire management: an appropriate regime, which encourages regeneration around the stand margins rather than increasing the edge-effects, needs to be devised. Given the geographic discontinuity with *Eucalyptus tenuiramis*, the southwestern copses may represent a relict dry sclerophyll community that was once contiguous with eastern Tasmania during the height of the last glaciation.
Key Words: ***Eucalyptus tenuiramis*, southwestern Tasmania, Louisa Bay.**

INTRODUCTION

Eucalyptus nitida is the dominant eucalypt species across most of lowland southwestern Tasmanian scrub boundaries and copses (Brown & Podger 1982, Jarman *et al.* 1982, 1988, Balmer 1990, Marsden-Smedley 1990, Marsden-Smedley *et al.* 2000a). However, there have been reports of an unusual eucalypt from the plains behind Louisa Bay for more than 20 years (R.G. Tyson, pers. comm.; J.B. Kirkpatrick, pers. comm.). These reports included a single photograph (pl. 1), which was taken by R.G. Tyson in the 1970s near Ningher Creek to the east of Louisa Bay, and was passed on to B. Potts at the Department of Plant Science, University of Tasmania, for identification. The picture showed what appeared to be a highly glaucous, mallee-form eucalypt (2–3 m tall) in the peppermint group (Series *Piperitae*, after Pryor & Johnson 1971). Although this is similar in appearance to either *Eucalyptus tenuiramis* or *E. coccifera*, the plains behind Louisa Bay fall well outside the climatic, substrate or geographic ranges of both species (Williams & Potts 1996).

Knowing that we were intending to visit Louisa Bay during a bushwalk in the late 1980s, B. Potts requested that we access the known population of this species and collect specimens for taxonomic identification and genetic studies. J. Kirkpatrick (Department of Geography, University of Tasmania) subsequently brought our attention to the more extensive stands of this eucalypt on the southern end of the Red Point Hills, to the west of Louisa Bay, which he had observed during flights between Hobart and Melaleuca. Therefore, it appeared that the species might more extensive than previously thought—occurring to both the east and west of Louisa Bay.

On those earlier walking trips, no glaucous eucalypts were seen adjacent to the route which is normally traversed on the way to Louisa Bay (from the Spica Hills south to the northwestern end of Louisa Beach). However, on a flight over the region in January 1992, we observed what Kirkpatrick had previously noted: an extensive mosaic of the species on the Red Point Hills to the west of Louisa Bay. We also observed several small stands of the glaucous eucalypt to the east of Louisa Bay, near where R.G. Tyson had reported it in the 1970s. The observation was fortuitous, occurring because the glaucous foliage reflected the late afternoon sun, temporarily distinguishing it from the bright-green foliage of the adjacent *Eucalyptus nitida*.

With the assistance of S. Corbett (Vegetation Mapper for the Southwest Wilderness World Heritage Area) and colour aerial photography, we identified a series of potential stands of this eucalypt. These were clearly well away from existing walking routes and would require a specific survey to access and collect specimens to clarify their identity. Previous discussions with M. Neyland (Forestry Tasmania) had suggested that the lowland plains below the Red Point Hills were covered by extensive bands of wet scrub, and that a better route might be via the summit of the Red Point Hills. This is the route we followed in our March 1996 survey. The primary objectives of the field survey were to collect herbarium voucher specimens (including fruit and seeds) for formal taxonomic identification and genetic studies. A secondary objective was to record the population status of the eucalypt and its associated habitat. An account of these findings is presented here. Due to its glaucous foliage, lowland distribution and superficial resemblance to *Eucalyptus tenuiramis*, we refer to the population by the name *Eucalyptus* aff. *tenuiramis* (Louisa

PLATE 1
Glaucous mallee-form eucalypt near Ningher Creek on the Louisa Plains. (Photograph taken by R. G. Tyson in the 1970s.)

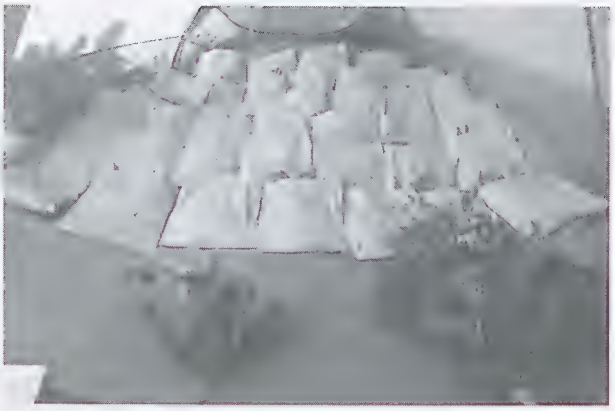

PLATE 3
Field drying of voucher specimens and capsules.

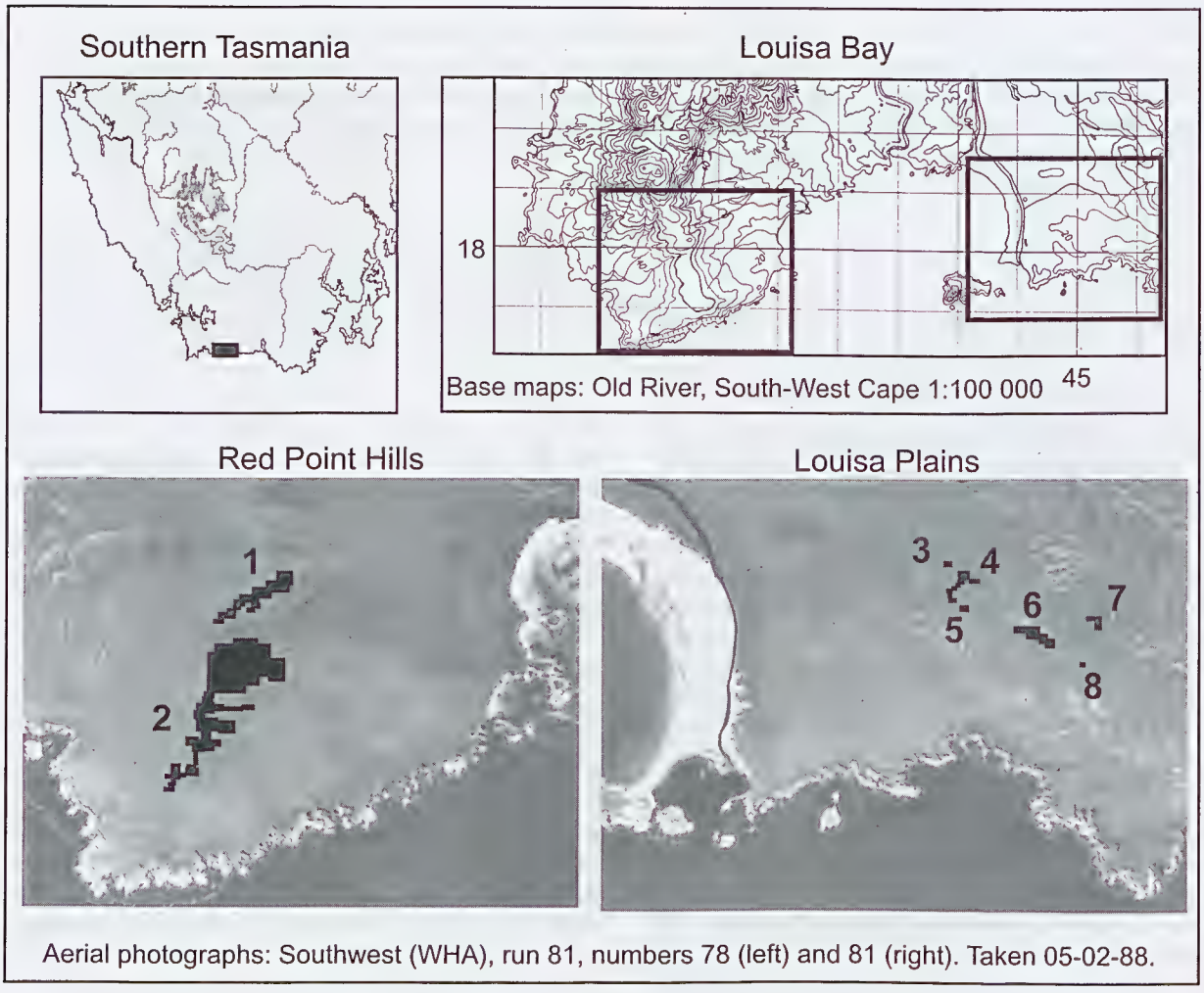

PLATE 2
Location of study area and individual copses of Eucalyptus *aff.* tenuiramis *(Louisa Bay) in the vicinity of Louisa Bay, southwestern Tasmania. Note: copse 7 is shown in pl. 1 while the copse sampled on the Red Point Hills is copse 1 and the copse sampled on the Louisa Plains is copse 6.*

Bay). Recent genetic studies based on the seed collected during this field reconnaissance survey indicated that this species is in fact a subspecies of *Eucalyptus tenuiramis* (Turner 1999).

METHODS

Study Area

The Red Point Hills and Louisa Plains are located on the south coast of Tasmania about 20 km southeast of Melaleuca in southwestern Tasmania (pl. 2). The region consists of undulating plains 20–60 m a.s.l., and low hills up to 275 m a.s.l. To the north and east the region is surrounded by higher country consisting of Mt Louisa and the Ironbound Range (about 950 and 800 m a.s.l. respectively). The region is underlain by Precambrian phyllite (Brown *et al.* 1995). The region has been included in the South-West National Park and forms part of the Tasmanian Wilderness World Heritage Area.

Potential stands were identified using 1:25 000 colour aerial photographs taken in 1988 (pl. 2). These stands were identified by their glaucous colouration and mallee to small-tree form, and were ranked by their likelihood of containing the target eucalypt. Potential stands were traced onto 1:25 000 topographic base maps for verification during the field reconnaissance survey.

Field Surveys

The field reconnaissance survey was undertaken between 4 and 7 March 1996, primarily to collect herbarium voucher and seed specimens from stands located both to the east (Louisa Plains) and west (Red Point Hills) of Louisa Bay. During this survey, two copses were sampled: copse 1 from the Red Point Hills and copse 6 from the Louisa Plains (pl. 2 and table 1). The population status, floristic composition and site conditions were also assessed.

Seed and voucher specimen collection

Seed in mature capsules were collected from six to ten non-adjacent individual trees. Capsules and representative leaves (fully expanded new seasons' growth) were stored in paper collection bags. Herbarium voucher specimens were collected from the same trees and arranged in a field press. Juvenile material was collected from coppice on these trees, where available, or from other individuals. Individual tree material was strictly separated and labelled. A description of each sampled tree (height, diameter, growth form) and its associated habitat (site conditions, dominant understorey species) were noted. The sampled trees were generally located within plots associated with each transect, but not exclusively.

Drying of voucher specimens and capsules was initiated under field conditions as far as practical (pl. 3). Voucher specimens were lodged with the Tasmanian Herbarium (table 2), while seed and capsule collections were lodged with the Department of Plant Science, University of Tasmania.

TABLE 1
Location and extent of the *Eucalyptus* aff. *tenuiramis* (Louisa Bay) in the vicinity of Louisa Bay

Number and location	Easting	Northing	Size (ha)	Stand type	Altitude	10K grid
1 Red Point Hills	443300	5180200	10	high density large copse	120	4418
2 Red Point Hills	443200	5179500	30	medium density scrub mosaic	70	4417
3 Louisa Plains	450300	5181300	1	small low copse	20	4518
4 Louisa Plains	450600	5181000	5	small low copse	20	4518
5 Louisa Plains	450500	5180700	2	small low copse	20	4518
6 Louisa Plains	451100	5180600	3	high density copse	40	4518
7 Louisa Plains	451400	5180700	2	small low copse	60	4518
8 Louisa Plains	451400	5180300	1	small low copse	40	4518
Total area			54			

TABLE 2
Voucher specimens *Eucalyptus* aff. *tenuiramis* (Louisa Bay) lodged with the Tasmanian Herbarium

Collection location	Identification numbers					
Red Point Hills	HO442472	HO442491	HO442493	HO442494	HO442495	HO442482
	HO442490	HO442492				
Louisa Plains	HO442333	HO442516	HO442517	HO442499	HO442500	HO442518

Descriptions of each seed tree are given in appendix 1. A full copy of the data collected has been lodged with the World Heritage Area Botanist, Department of Primary Industries, Water and Environment.

Population ecology

The relative health and regeneration status of rare taxa are of particular interest for conservation management planning. This field survey aimed to evaluate aspects of the population ecology of the target eucalypt using one transect in each of the copses sampled (see above). Each transect was located normal to the moorland–copse boundary and sampled by contiguous 10 x 10 m plots from moorland through forest to moorland on the opposite side. Seven plots were located along the Red Point Hills transect (70 m), and six plots along the Louisa Plains transect (60 m). At each plot, floristic composition and vegetation structure were recorded along with site conditions and eucalypt population status (table 3). With the exception of the glaucous eucalypt described in this paper, which has been termed *Eucalyptus* aff. *tenuiramis* (Louisa Bay), species terminology follows Buchanan (1995).

A numerical index, in five levels, was used to describe individual tree "healthiness" (1 = good; 2 = medium to good; 3 = medium to poor; 4 = poor; 5 = dead). Individual tree health was subjectively assessed by observing the integrity of leaf margins (i.e. degree of herbivory), density of galls, leaf colour, lesions and blemishes (e.g. degree of stress-induced redness or microbial disease), vigour and abundance of new season's growth, and presence or abundance of coppice regrowth (indicating loss of apical dominance by crown).

A descriptive account of the trends in population status of *E.* aff. *tenuiramis* for each transect was based on observations of stem density, canopy height, stem diameter, growth stage and overall plant health within each 100 m^2 plot. The trend in substrate depth is shown for the Red Point Hill transect, but was not measured at the Louisa Plains transect (because the wire pin was lost in the scrub between sites).

Floristic trends

Trends in the change in vascular plant species with distance along each transect were recorded. Floristic associations are described and compared with published accounts of comparable vegetation types from dry sclerophyll (Duncan & Brown 1985) and moorland (Jarman *et al.* 1988).

RESULTS

Aerial Photograph Interpretation

Aerial photograph interpretation indicated about 54 ha of the glaucous eucalypt in eight patches (pl. 2, table 1). Most of the area (30 ha) was attributed to one large mosaic of the glaucous eucalypt interspersed by small areas of wet scrub in the vicinity of the Red Point Hills. The Louisa Plains population was notably dispersed and local among several small stands, whereas the Red Point Hills population was more contiguous across the low hills above Contact Cove.

Field Surveys

Population ecology

The overall trends in tree size and growth stage observed for the two eucalypt populations are given in figure 1. The Red Point Hills population had a larger proportion of multi-stemmed adult individuals and fewer juveniles than the Louisa Plains population. In both populations, growth stages were dominated by juveniles, coppice or mallee-form trees at the moorland–copse boundary, whereas larger, single-stemmed trees dominated towards the centre of each copse.

Trends in stand performance (mean canopy height, basal area, stem density and relative health) of the *E.* aff. *tenuiramis* populations along the Red Point Hills and Louisa Plains transects are displayed in figures 2 and 3, respectively. In each case, mean stand canopy height diminished to less than 2 m at the copse–moorland boundary and increased to about 12 m toward the centre of each copse. Mean tree basal area also varied from the margin to the centre of the copse, from about 30 cm^2 per 100 m^2 (tree diameters of 5–6 cm) to about 800 cm^2 per 100 m^2 (about 30 cm diameter). Our subjective assessment of stand health also indicates that less optimal growing conditions were experienced by individuals located adjacent to the moorland than at the centre of the copse.

The soils of both copses were generally shallow, being shallowest on the northern aspects where the substrate seemed almost skeletal on bedrock and gravel. Variation in substrate depth was observed at the Red Point Hills site (fig. 4). Substrate depth closely corresponded with trends

TABLE 3

Survey methods used to assess floristic composition and population status of *Eucalyptus* aff. *tenuiramis* (Louisa Bay)

Attribute	Description of method
Vegetation structure	Estimated height, projective-foliage cover and species dominance ranking in major structural layers: tree, shrub and ground strata.
Floristic composition	Floristic list of all vascular plant species with Braun-Blanquet percentage cover-abundance ratings.
Eucalypt population ecology	Height and diameter (stem above basal swelling) of each individual in 10 x 10 m plots, number and size of individual stems if mallee-form, presence or absence of lignotuber, tree health index (1 = good – 5 = dead, see text), reproductive status (juvenile, coppice, adult-vegetative, adult-reproductive).
Site conditions	Substrate penetrability using a 3 mm wire probe (up to 1.0 m), slope, aspect, local terrain position, approximate time since fire (*Banksia* node counts and *Leptospermum* ring counts).

in eucalypt tree size and density. Relatively shallow soils (< 50 cm depth) generally corresponded with increasing basal area and height of the copse. At moorland–copse boundaries, substrate depths increased abruptly, and in the moorland proper, the peat soils were very deep (> 1.0 m) and frequently quaked at each step.

Trends in fire age were observed from the number of branch nodes of *Banksia marginata* and basal ring counts from *Leptospermum* spp., as well as fire history mapping from aerial photographs (Marsden-Smedley 1998). These indicated that both the sites were burnt in 1933/34, with the Red Point Hills population subsequently being burnt in 1948 and partly in 1976 (the fire did not penetrate to the centre of the copse, appendix 2). These differences in fire history may have some relationship to observed differences in stand structure and health (figs 1–3).

Floristic trends

A list of the vascular plant species recorded along each transect and their relative abundance are given in appendix 3. The vegetation at the centre of the *E.* aff. *tenuiramis* copses is best described as closed wet scrub. Turnover in species composition along transects is associated with distance from the moorland–copse boundary and changes in substrate

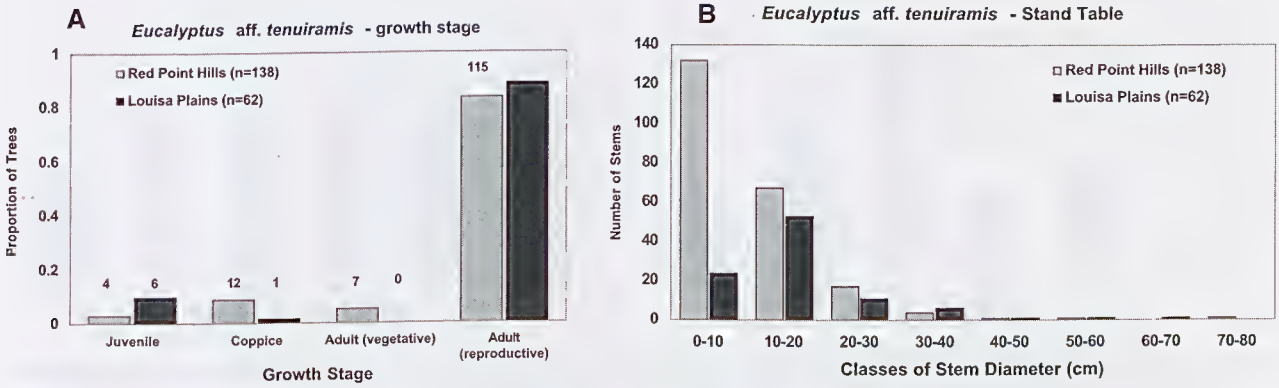

FIG. 1 — Trends in (A) growth stage and (B) stem diameter of E. *aff.* tenuiramis *(Louisa Bay) for the two transects. Numbers on graphs indicate sample size.*

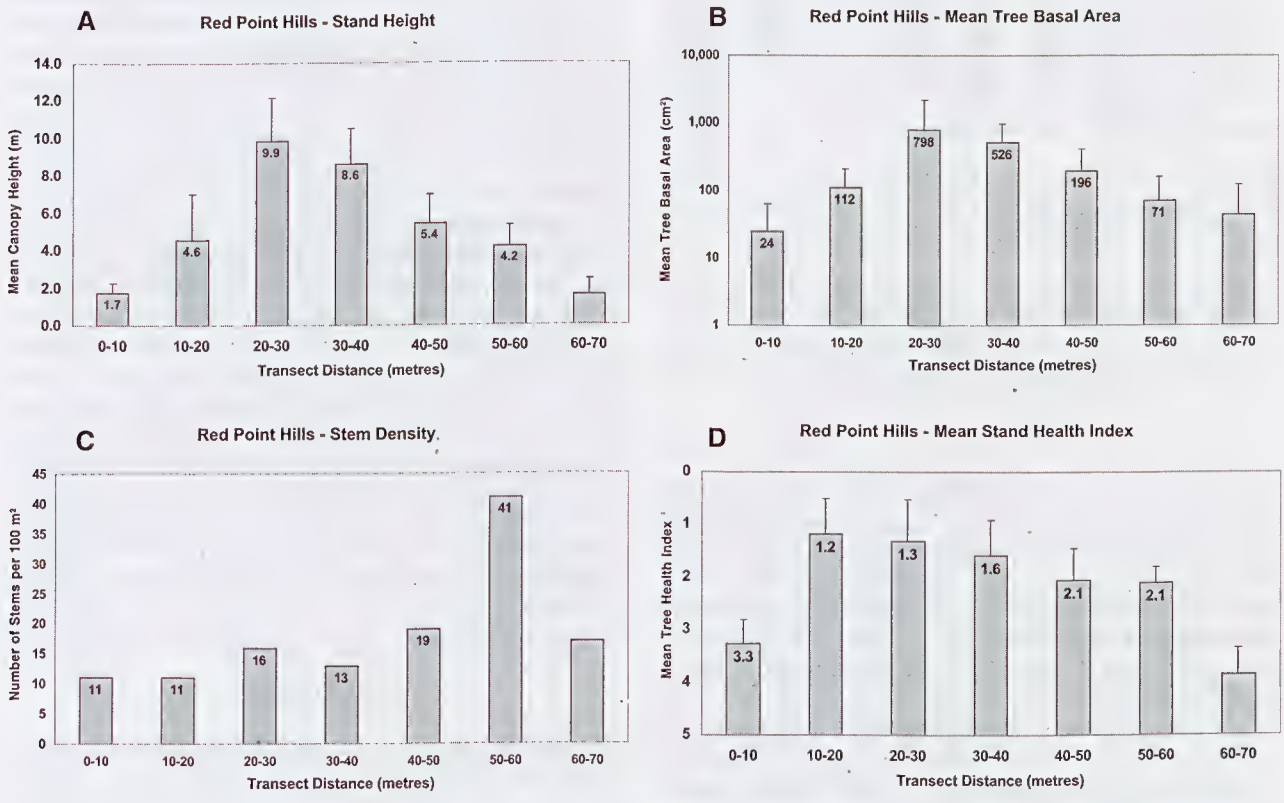

FIG. 2 — Trends in performance of the Red Point Hills population of Eucalyptus *aff.* tenuiramis *(Louisa Bay): (A) canopy height, (B) stand basal area, (C) stem density and (D) stand health index (see text, p.48). Error bars indicate standard deviation.*

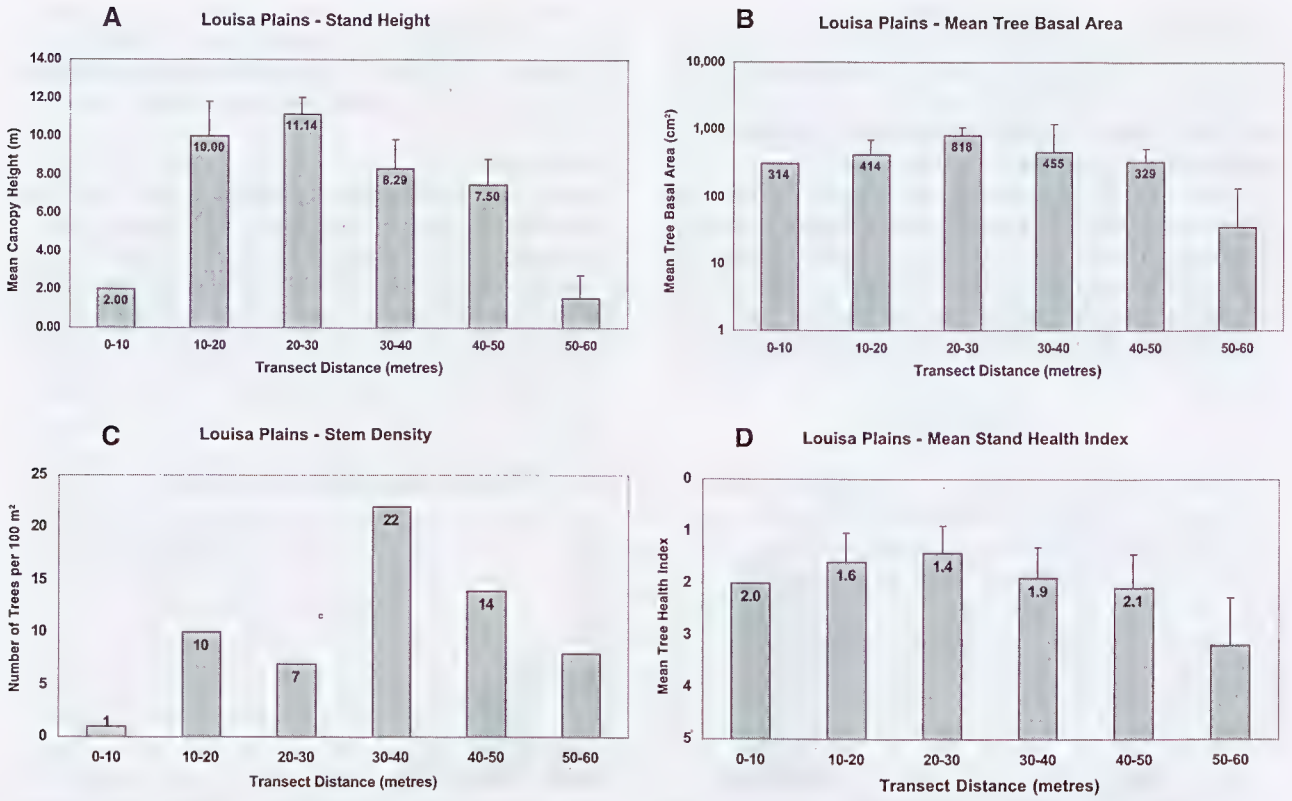

FIG. 3 — Trends in performance of the Louisa Bay population of Eucalyptus *aff.* tenuiramis *(Louisa Bay): (A) canopy height, (B) stand basal area, (C) stem density and (D) stand health index. Error bars indicate standard deviation.*

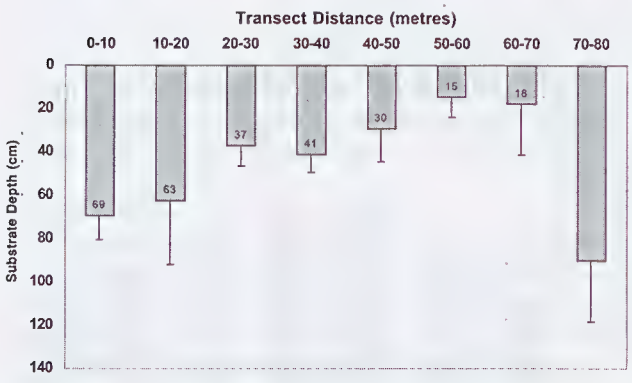

FIG. 4 — Trends in substrate depth along the Red Point Hills transect. Error bars indicate standard deviation.

depth and soil type. These changes are typical of woodland copses surrounded by moorland (e.g. Jarman *et al.* 1988, Marsden-Smedley 1990, Marsden-Smedley *et al.* 2000a). However, although the vegetation of the copses dominated by *E.* aff. *tenuiramis* floristically differed from those previously described for *E. nitida,* its closest affinities appear to be with the Dry-domed Copse (Type 12B) community types described by Jarman *et al.* (1988).

The copse vegetation was dominated by dense stands of *E.* aff. *tenuiramis* with a wet scrub understorey comprising species such as *Gahnia grandis* and *Zieria arborescens,* which are commonly found in disturbed wet forests following fire. Wet scrub species, such as *Melaleuca squarrosa, Banksia marginata* and *Baueria rubioides,* which are commonly found across moorland–copse boundaries, tended to occur throughout the copse, only declining in density toward the centre. The occurrence of these species further reinforced the suggestion that recurrent fire and the small size of the stands resulted in edge effects that penetrate throughout the copse, declining in intensity toward the centre.

Less common shrub and heath species included *Monotoca glauca, Epacris impressa, Leucopogon collinus, Pultenaea daphnoides, P. juniperina, Acacia myrtifolia* and *Pimelea linifolia.* These may represent relicts of the former forest type that might be more abundant if the patch sizes had been large enough to dissipate the edge effects. The lilies *Drymophila cyanocarpa* and *Dianella tasmanica* and the bracken fern *Pteridium esculentum* were also considered indicator species of the relict vegetation type. It appears that the relict vegetation type might have been a drier forest or open woodland than is at present typical of copses dominated by *Eucalyptus nitida* in southwestern Tasmania. Several species that are more typical of wet scrubs and woodland mosaics in southwestern Tasmania were also found in the copses. The most abundant species of this sort were *Lomatia polymorpha* and *Acacia verticillata. Lomatia polymorpha* appeared to fill the niche of its eastern relative *L. tinctoria.*

DISCUSSION

The copse vegetation appeared more typical of a drier forest type, such as might be found in southeastern Tasmania (Duncan & Brown 1985) than that expected of a typical buttongrass moorland copse (Jarman *et al.* 1988, Marsden-Smedley *et al.* 2000a). This observation was based on

indicator species with low abundances such as *Leucopogon collinus, Pulteneaea daphnoides* and *Acacia myrtifolia,* and the fact that individuals of the glaucous eucalypt appeared most like the southeastern forms of *E. tenuiramis* in dry sclerophyll forest. This might be consistent with the relict origin of this species from habitats that were once contiguous with eastern Tasmania (Turner 1999).

On the moorland–copse boundary, individuals of *E.* aff. *tenuiramis* were small in stature and frequently mallee-form. Toward the centre of the forest copse, they were taller (10–12 m) and straight with single, slender main stems. Juvenile leaves, buds and fruit, in particular, were highly glaucous and even the thick, shiny adult leaves were waxy.

The relative health and regeneration status of the two eucalypt populations from Louisa Plains and Red Point Hills differed. The smaller Louisa Plains population was most notable for the heavy load of seed-capsules from the previous year — weighing down the slender branches, but there were relatively few buds for the current year and virtually no new season's growth. By contrast, a much lighter seed crop was observed from the Red Point Hills population and abundant new growth was apparent. The distribution of size classes for stem diameters from the Red Point Hills stand (fig. 1B) indicated that several regeneration events had occurred in the recent past which are probably related to the fire events in 1933/34, 1948 and 1976. By contrast, the lack of similar regeneration as small size classes (0-10 cm basal stem diameter) at the Louisa Plains stand (last burnt in 1933/34) suggests a dependence on fire for seedling establishment. However, the Louisa Plains stand is also smaller than the Red Point Hills site, resulting in edge effects that may further contribute to the overall poorer health of individual trees (fig. 3D).

These results suggest that the long-term viability of *E.* aff. *tenuiramis* on Louisa Plains maybe questionable, due to its small area and the dispersed nature of its stands. The more extensive mosaics of the glaucous eucalypt on the Red Point Hills are likely to be more secure over the long term. It is also possible that other unknown relict species or genotypes of the former vegetation type may co-exist with the eucalypt in this area, and/or in similar habitats near by. For example, one of the authors (JM-S), has observed a similarly highly glaucous eucalypt on the lower slopes of Mt Wright in the Vale of Rasselas (J. M-S, pers. obs.).

The observations described in this paper have implications for fire management in the vicinity of Louisa Bay and the Red Point Hills, where a trade-off may exist between capacity to regenerate and edge effects. An appropriate fire regime, which encourages regeneration around the stand margins rather than increasing the edge-effects, needs to be devised. Such a fire regime could potentially be implemented through prescribed burning in the vicinity of these stands during periods of low fire danger and when soils are saturated (e.g. when the Moorland Fire Danger Rating and Soil Dryness Rating are both below five — Marsden-Smedley *et al.* 2000).

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APPENDIX 1
Location and description of each seed tree

Tree_id*	Easting	Northing	Altitude (m)	Height (m)	Glaucousness	Form Description	Stem1 (cm)	Stem2 (cm)	Site Description	Reproductive status	Comments
R_Tree1	443400	5180200	120	4 to 5	sub-glaucous	Mallee, 2-major branches from lignotuber, other branches dead	10	5	Edge of moorland	Moderate seed crop	-
R_Tree2	443450	5180150	120	4 to 5	sub-glaucous	Mallee, one small, one large stem	20	2	-	-	-
R_Tree3	443300	5190150	120	6	glaucous stems, otherwise subglaucous	single stem sapling	-	-	Tall scrubby-forest	-	-
R_Tree4	443300	5180200	120	6 to 8	-	20 to 25 cm diameter at base, 80 cm to bole then two branches	15	5	-	-	-
R_Tree5	443450	5180050	120	6 to 8	-	35 cm basal diameter, single stem, second branch at 1.5 m height - dead	35	-	Tall scrub *Banksia/ Melaleuca* understorey 6-8 m, with *Zieria/ Monotoca* 4-6 m	-	-
R_Tree6	443450	5180050	120	8 to 10	-	Two main stems	35	25	Wet scrub forest, dense canopy of *E.* aff. *tenuiramis* 60% FPC	-	-
R_Tree7	443450	5180050	120	10 to 12	-	Single stem - basal stem diameter	35	-	Scrub *Melaleuca* forest, open dark understorey	-	-
R_Tree8	443550	5180000	120	1 to 1.5	-	Mallee	-	-	Scrub-moorland	-	-
R_Tree9	443450	5180200	120	4 to 6	-	One main stem 15-20 cm diameter	15-20	-	Low mallee-scrub, third tree in from moorland edge	-	-
L_Tree10	451100	5180450	40	4 to 5	sub-glaucous	Mallee, 3 to 4 main stems	-	-	Copse edge	Heavy crop of seed from previous year - drought?	Moderate to poor health
L_Tree11	451100	5180600	40	7	-	Small tree, single stem	15-20	-	Distance - 6 to 10 trees from toward centre of copse from Tree10	-	-
L_Tree12	451100	5180600	40	10	-	Small tree, single stem	25	-	Middle of copse, steep slope, scrubby wet forest	-	-
L_Tree13	451100	5180600	40	9	-	Small tree	25	-	Middle of copse, steep slope, scrubby wet forest	-	-
L_Tree14	451100	5180600	40	10	-	Small tree	25	-	Near lower southern boundary of copse, sedgey closed forest understorey	-	-
L_Tree15	451100	5180600	40	4	-	Small tree, several stems 5-10 cm from a 1-2 m diameter lignotuber	25	-	Off ridge on edge of moorland	Heavy seed crop, some branches laden with fruit	-

* R = Red Point Hills, L = Louisa Plains.

APPENDIX 2
Site conditions recorded along the Red Point Hills and Louisa Plains transects

	Red Point Hills Transect							Louisa Plains Transect					
	0-10	10-20	20-30	30-40	40-50	50-60	60-70	0-10	10-20	20-30	30-40	40-50	50-60
Site Condition	R1	R2	R3	R4	R5	R6	R7	L1	L2	L3	L4	L5	L6
Last Fire (year)	1976	1976	1976	1948	1948	1976	1976	1933/ 1934	1933/ 1934	1933/ 1934	1933/ 1934	1933/ 1934	1933/ 1934
Soil depth (cm)	69	63	37	41	30	15	18	-	-	-	-	-	10
Aspect (deg.)	180	135	250	260	260	290	320	200	200	210	280	155	155
Slope (deg.)	6	2	1	2	5	15	15	9	20	20	2	5	2
Altitude (m a.s.l.)	120	120	125	130	125	120	120	40	40	45	40	35	30

APPENDIX 3
Vascular plant species composition along the Red Point Hills and Louisa Plains transects

	Red Point Hills Transect							Louisa Plains Transect					
	0-10	10-20	20-30	30-40	40-50	50-60	60-70	0-10	10-20	20-30	30-40	40-50	50-60
Species*	R1	R2	R3	R4	R5	R6	R7	L1	L2	L3	L4	L5	L6
Eucalyptus aff. *tenuiramis*	2.5	15	62.5	62.5	62.5	87.5	15	1	62.5	62.5	62.5	37.5	2.5
Melaleuca squarrosa	38	37.5	37.5	37.5	15	0	0	38	37.5	2.5	62.5	37.5	0
Monotoca glauca		0	15	15	15	1	0	0	0	0	2.5	0	0
Gahnia grandis	0	15	2.5	15	15	15	0	0	37.5	62.5	37.5	37.5	0
Zieria arborescens	0	0	2.5	15	15	2.5	0	0	15	2.5	2.5	1	0
Banksia marginata	2.5	37.5	0	15	15	37.5	37.5	15	1	0	2.5	37.5	15
Acacia verticillata	0	1	15	2.5	37.5	15	0	0	15	37.5	0	37.5	1
Leptospermum scoparium	15	2.5	2.5	2.5	37.5	37.5	15	0	0	0	0	0	2.5
Bauera rubioides	0	2.5	0	2.5	37.5	37.5	2.5	88	1	1	2.5	15	15
Lomatia polymorpha	0	0	0	2.5	2.5	2.5	1	1	62.5	2.5	2.5	2.5	2.5
Cenarrhenes nitida		0	15	2.5	0	1	0	0	0	0	0	0	0
Pteridium esculentum	0	0	1	1	1	0	0	0	0	0	2.5	2.5	0
Dianella tasmanica	0	0	0	1	0	2.5	0	0	0	0	2.5	1	0
Billardiera longifolia	0	0.5	0.5	0.5	1	0	0	0	1	0	2.5	2.5	0
Ehrharta tasmanica	0	0	0	0.5	1	1	0	0	0	0	0	0	0
Drymophila cyanocarpa	0	0	1	0.5	0	0	0	0	0	0	0.5	0	0
Blechnum wattsii	0	0	0	0.5	0	0	0	0	0	1	1	0.5	0
Gonocarpus teucrioides	0	0	0	0.5	0	1	0	0	0	0	0	0	0
Phyllocladus aspleniifolius	0	0	0	0.5	0	0	0	0	0	0	0	0	0
Pimelea linifolia	1	1	0	0.5	0	1	0	0	0	0	0	0	0
Agastachys odorata	15	15	0	0	2.5	2.5	0	0	0	0	0	0	0
Lycopodium fastigatum	0	1	0	0	2.5	0	0	0	0	0	0	0	0
Phebalium squameum	0	0	0	0	2.5	1	0	0	2.5	0	0	0	0
Cyathodes juniperina	0	0	1	0	1	0	0	0	0	0	0	0	0
Boronia citriodora	2.5	2.5	0	0	1	0	1	0	0	0	0	0	0
Empodisma minus	1	2.5	0	0	1	1	2.5	2.5	0	1	0	0	2.5
Epacris impressa	0	0	0	0	1	2.5	0	0	0	0	0	0	2.5
Schoenus tenuissimus	1	1	0	0	1	1	0	0	0	0	0	0	1
Sprengelia incarnata	1	1	0	0	1	0	1	0	0	0	0	0	1
Tasmannia lanceolata	0	0	0.5	0	0	0	0	0	0	0	0	0	0
Acacia myrtifolia	0	0	0	0	0	0	1	0	0	0	0	0	1
Allocasuarina monilifera	0	0	0	0	0	0	37.5	15	0	0	0	0	37.5
Anopterus glandulosus	0	0	0	0	0	0	0	0	0	2.5	0.5	0	0
Baumea tetragona	1	0	0	0	0	0	0	0	0	0	0	0	0
Cassytha glabella	0	0	0	0	0	0	0	0	0	0	0	1	0
Epacris lanuginosa	0	2.5	0	0	0	0	1	0	0	0	0	0	0
Diplarrena latifolia	0	0	0	0	0	0	0	0	1	0	0	1	1
Epacris heteronema	0	0	0	0	0	0	1	0	0	0	0	0	0
Lindsaea linearis	0	0	0	0	0	0	1	0	0	0	0	0	0
Gleichenia dicarpa	1	1	0	0	0	1	37.5	2.5	1	37.5	15	2.5	0
Gymnoschoenus sphaerocephalus	38	1	0	0	0	0	15	0	0	0	0	0	1
Hakea epiglottis	0	0	0	0	0	0	0	0	0	0	0	0	15
Leucopogon collinus	0	0	0	0	0	0	2.5	0	0	0	0	0	2.5
Lepidosperma ensiforme	0	0	0	0	0	0	0	0	0	0	15	1	0
L. filiformis	0	0	0	0	0	0	2.5	0	0	0	0	0	15
Leptospermum nitidum	2.5	0	0	0	0	0	2.5	0	0	0	0	0	0
Leptocarpus tenax	2.5	0	0	0	0	0	2.5	0	0	0	0	0	0
Lepyrodia sp.	1	0	0	0	0	0	0	0	0	0	0	0	0
Melaleuca squamea	15	37.5	0	0	0	0	2.5	0	0	0	0	0	0
Moss	0	0	0	0	0	0	0	0	0	2.5	1	0	0
Patersonia fragilis	0	0	0	0	0	0	1	0	0	0	0	0	0
Persoonia juniperina	0	0	0	0	0	0	2.5	0	0	0	0	0	0
Pomaderris apetala	0	0	0	0	0	0	0	0	0	37.5	0	0	0
Pultenaea daphnoides	0	0	0	0	0	2.5	0	0	0	0	0.5	0	0
P. juniperina	0	0	0	0	0	0	0	0	0	0	0	0.5	0
Restio complanatus	0	0	0	0	0	0	1	0	0	0	0	0	0
R. hookeri	0	0	0	0	0	0	2.5	0	0	0	0	0	0
Stylidium graminifolium	0	0	0	0	0	0	1	0	0	0	0	0	0
Xyris sp.	1	1	0	0	0	0	0	0	0	0	0	0	0

* Nomenclature and synonyms follow Buchanan 1995, except *Eucalyptus* aff. *tenuiramis*. Percentage cover-abundances follow Braun-Blanquet scores in Mueller-Dombois & Ellenberg (1974).

THREATENED TRICHOPTERA (CADDISFLIES) FROM THE TASMANIAN WILDERNESS WORLD HERITAGE AREA

by Jean Jackson

(with one table and two appendices)

JACKSON, J., 2000 (31:xii): Threatened Trichoptera (caddisflies) from the Tasmanian Wilderness World Heritage Area. *Pap. Proc. R. Soc. Tasm.* 134: 55–62. ISSN 0080–4703. Inland Fisheries Service, PO Box 288, Moonah, Tasmania, Australia 7009.

Trichoptera were collected in the Tasmanian Wilderness World Heritage Area (WHA) between November 1998 and February 1999 using automatic UV light traps, sweep nets and aquatic hand-picking. The surveys targeted the four species listed on the Tasmanian *Threatened Species Protection Act* 1995 which had been recorded from the WHA: *Taskiria mccubbini, Taskiropsyche lacustris* (both endangered), *Orphninotrichia maculata* (rare) and *Oxyethira mienica* (rare). In total 88 species were identified, approximately half of the 174 species now known from Tasmania. *Taskiria mccubbini* and *Taskiropsyche lacustris* were recorded for the first time since they were first collected from the original Lake Pedder in 1965. *Orphninotrichia maculata* was recorded from a new location. *Diplectrona lyella* (rare) was recorded from two widely separated sites and is a new threatened species record for the WHA. One species of Ecnomidae was newly recorded from Tasmania.

Key Words: aquatic insects, Trichoptera, caddisflies, Tasmanian World Heritage Area, threatened species, Tasmania.

INTRODUCTION

Trichoptera (caddisflies) are a diverse group of aquatic insects, with 174 species now known from Tasmania (Neboiss *et al.* 1989, Schmid 1989, Jackson 1998, Wells 1998, S.J. Chilcott, pers. comm., this study). Prior to this study, four species listed on the Tasmanian *Threatened Species Protection Act* 1995 were known to occur in the Tasmanian Wilderness World Heritage Area (WHA). Two of these, the Lake Pedder caddisfly, *Taskiropsyche lacustris*, and McCubbins caddisfly, *Taskiria mccubbini*, are listed as endangered and have not been collected from their only known location at Lake Pedder since it was flooded in 1972. The other threatened species, the spotted microcaddisfly, *Orphninotrichia maculata*, and the Miena microcaddisfly, *Oxyethira mienica*, are listed as rare. They are known from only a few widely dispersed locations. The aim of the surveys reported here was to assess the distribution and conservation status of the four threatened Trichoptera species from the WHA and to increase knowledge of the distribution of all the species collected.

METHODS

Collections were made at 34 sites in or near the WHA. Sampling areas were along the Lyell Highway, Lake Pedder shore (access by boat), Scotts Peak Dam Road and Gordon Road. Localities and dates of samples are given in table 1. All Trichoptera specimens are lodged in the Museum of Victoria.

A range of sampling methods was used with the aim of collecting a wide range of species. Some species are not attracted to UV light traps (A. Wells, pers. comm.) and identifiable immatures are sometimes collected where no adults are found. At each site, a free-standing automatic UV light trap was run overnight near the stream or lake. These traps used blacklight tubes powered by a 12V gel cell battery and collected specimens into 70% ethanol. Sweep net samples were also taken by sweeping riparian vegetation with a fine mesh net (Australian Entomological Supplies) for 20 min. Immature stages of Hydroptilidae were targeted by hand-picking from substrates in the water for at least 10 min. If hydroptilids were found, the sample time was usually extended. In addition, opportunistic hand-samples of adults were obtained at a few sites.

Although the aim was to sample most sites twice by all three methods, some were sampled once opportunistically and sampling was limited at times by malfunctioning of light traps or heavy rain preventing sweep netting.

RESULTS

Species Recorded

From more than 4480 adult specimens and several hydroptilid larvae and pupae, 88 species were identified. In addition some specimens (mainly females) were of indeterminate genus or species. Some species were collected in large numbers, others as only single specimens. The species collected are given by site and date in appendices 1 and 2. Full details of sexes, numbers and methods are presented in Jackson (1999).

Threatened Species

Four threatened species were collected (*Taskiria mccubbini, Taskiropsyche lacustris, Orphninotrichia maculata, Diplectrona lyella*) with another being tentatively identified (*Hydrobiosella ?armata*). There were very few specimens of these threatened species. It is noteworthy that *O. maculata* was not collected from the Wedge River, where it had previously been recorded several times (Neboiss *et al.* 1989); the new record is from a new site. The other rare species previously known from the WHA, *Oxyethira mienica*, was not collected as adult males or developed male pupae, which are required for identification. *Oxyethira* sp. larvae and adult females were collected at five sites, but these cannot be identified to species (Wells 1997). Unfortunately, the exact site of the

TABLE 1
Localities and dates of samples taken for Trichoptera

Site–date no.	Date	Site name	Easting*	Northing*
1	2–3 Nov 98	Navarre River at Lyell Hwy	430200	5329300
2	16–17 Feb 99	Navarre River at Lyell Hwy	430200	5329300
3	2–3 Nov 98	Franklin River upstream of Lyell Hwy bridge	419000	5325700
4	16 Feb 99	Franklin River upstream of Lyell Hwy bridge	419000	5325700
5	2–3 Nov 98	Collingwood River downstream of Lyell Hwy bridge	411300	5331400
6	16 Feb 99	Collingwood River downstream of Lyell Hwy bridge	411300	5331400
7	2–3 Nov 98	Cardigan River upstream of Lyell Hwy bridge	403400	5335300
8	16–17 Feb 99	Cardigan River upstream of Lyell Hwy bridge	403400	5335300
9	2–3 Nov 98	Nelson River downstream of Lyell Hwy bridge	395300	5337700
10	2–3 Nov 98	Nelson River at base of Nelson Falls	395400	5338200
11	16–17 Feb 99	Nelson River downstream of Raglan Range bridge	395000	5327700
12	11 Nov 98	Broken Leg Creek at Lyell Hwy	440200	5336800
13	24–25 Nov 98	Maria Creek near Lake Pedder	441900	5250400
14	10 Feb 99	Maria Creek near Lake Pedder	441900	5250400
15	24–25 Nov 98	Pebbly Creek about 50 m upstream of Lake Pedder	435300	5239800
16	10 Feb 99	Pebbly Creek about 50 m upstream of Lake Pedder	435300	5239800
17	24–25 Nov 98	Frankland shore stream near Lake Pedder	431400	5241800
18	10 Feb 99	Frankland shore stream near Lake Pedder	431400	5241800
19	24–25 Nov 98	stream south of Timber Creek, Lake Pedder	426600	5245700
20	10 Feb 99	stream south of Timber Creek, Lake Pedder	426600	5245700
21	24–25 Nov 98	Bonnet Bay small creek, upstream of Lake Pedder	430200	5249100
22	10 Feb 99	Bonnet Bay small creek, upstream of Lake Pedder	430200	5249100
23	21 Jan 99	Bonnet Bay large creek, upstream of Lake Pedder	432000	5249100
24	24–25 Nov 98	Lake Pedder shore north of Forest Creek	422100	5249700
25	10 Feb 99	Lake Pedder shore north of Forest Creek	422100	5249700
26	21 Jan 99	Lake Pedder between Strathgordon and Bonnet Bay	–	–
27	26 Nov 98	Lake Pedder shore near Serpentine boat ramp	416900	5264100
28	4 Mar 99	Lake Pedder shore near Serpentine boat ramp	416900	5264100
29	26 Nov 98	Dozer Creek about 100 m downstream of Gordon Rd	430500	5257000
30	4 Mar 99	Dozer Creek about 100 m downstream of Gordon Rd	430500	5257000
31	26 Nov 98	Teds Beach near southern corner, Lake Pedder	423100	5262100
32	4 Mar 99	Teds Beach near southern corner, Lake Pedder	423100	5262100
33	14 Jan 99	small stream about 100 m W of Teds Beach turnoff, Gordon Rd	423200	5262300
34	14 Jan 99	small stream about 300 m E of Teds Beach turnoff, Gordon Rd	423200	5262000
35	13 Jan 99	stream E of Spring St houses, Strathgordon	421800	5264600
36	16 Dec 98	Strathgordon jetty, Lake Pedder	422200	5264300
37	1–2 Dec 98	Little Florentine River upstream of Gordon Rd	452700	5267900
38	26–27 Jan 99	Little Florentine River upstream of Gordon Rd	452700	5267900
39	1–2 Dec 98	unnamed river E of Boyd River, Gordon Rd	445300	5258900
40	26–27 Jan 99	unnamed river E of Boyd River, Gordon Rd	445300	5258900
41	1–2 Dec 98	Wedge River near picnic area	437200	5254400
42	26–27 Jan 99	Wedge River upstream of Gordon Rd, in rainforest	437100	5254400
43	26–27 Jan 99	Wedge River upstream of Gordon Rd, open reach	437000	5254400
44	1–2 Dec 98	Red Tape Creek downstream of Scotts Peak Rd	448200	5236650
45	26–27 Jan 99	Red Tape Creek downstream of Scotts Peak Rd	448200	5236650
46	1–2 Dec 98	unnamed creek 3.8 road km N of Red Tape Creek, Scotts Peak Dam Rd	448600	5239800
47	26–27 Jan 99	unnamed creek 3.8 road km N of Red Tape Creek, Scotts Peak Dam Rd	448600	5239800
48	1–2 Dec 98	Condominium Creek Scotts Peak Dam Rd	447800	5243400
49	26–27 Jan 99	Condominium Creek Scotts Peak Dam Rd	447800	5243400
50	1–2 Dec 98	Gelignite Creek Scotts Peak Dam Rd	449300	5251300
51	26–27 Jan 99	Gelignite Creek Scotts Peak Dam Rd	449300	5251300
52	10 Mar 99	Lake Oberon Western Arthur Range, top of plain	440400	5222500

* The eastings and northings are Australian Map Grid references, accurate to 100 m.

previous *O. mienica* record from Scotts Peak Dam Road is unknown.

New Records for Tasmania

Ecnomus turgidus was recorded from Tasmania for the first time; this species is widespread in southern Australia (Cartwright 1990).

Undescribed Species

Ecnomina sp. nov. was first collected from the Frankland shore of Lake Pedder in 1988 (Chilcott 1988) and the same species has been found at additional sites in the present study (A. Neboiss, pers. comm.).

Other Significant Records

Cased larvae and pupae of *Maydenoptila explicata* had not been collected before; the larvae are possibly long-lived as their sand-grain cases are covered in filamentous algae (A. Wells, pers. comm.). Four species are new records for the WHA (Neboiss *et al.* 1989): *Diplectrona lyella, Hellyethira malleoforma, H. basilobata* and *Ulmerochorema lentum.*

DISCUSSION

This study has added significant new records to the Tasmanian and WHA trichopteran fauna. Aspects of special interest are discussed below.

Conservation Status

The conservation status of the threatened species collected was assessed against *Guidelines for the listing of species under the Tasmanian Threatened Species Protection Act* 1995 (*Tasmanian Government Gazette* no. 19 852, March 25, 1998). The kokiriids *Taskiropsyche lacustris* and *Taskiria mccubbini* are each known from a single existing site from this survey, and were not recorded in previous surveys of the area (Chilcott 1988, Neboiss *et al.* 1989). They qualify as endangered due to the estimated small total number of individuals. This estimate is based on the failure to collect the species for over 30 years and the collection of so few specimens in this study (one *Taskiropsyche lacustris* and two *Taskiria mccubbini*). There has been a presumed past population decline with the loss of habitat under the Lake Pedder impoundment and potential threats remain. The *T. mccubbini* site on the shore of the Lake Pedder impoundment may be affected by fluctuating water levels and the impoundment now contains large predatory fish (brown trout, *Salmo trutta*). The *Taskiropsyche lacustris* site near Gordon Road could be affected by any roadworks in the area.

Orphninotrichia maculata is now known from three disjunct sites, of which only one (Gelignite Creek) is fully reserved. Therefore, the species remains subject to potential threats such as vegetation clearing and water pollution. The species meets criteria for classification as rare due to the small number of populations. Interestingly, *O. maculata* is common and widespread on mainland Australia (A. Wells, pers. comm.) but was not collected by Neboiss (1977). The species may be quite widespread in Tasmania, although not often collected because it is seldom attracted to light. It is most easily collected by sweeping of vegetation near waterfalls and cascades (A. Wells, pers. comm.).

Diplectrona lyella was previously known from Hellyer Gorge and an unspecified site on the King River (Neboiss 1977) which may have been inundated by Lake Burbury. One of the two sites recorded in this study (Little Florentine River) is unreserved. The species qualifies as rare due to the small number of known populations.

Collecting Methods

By far the majority of species and specimens were collected in the light traps. However, valuable additions to the species list were made by sweep netting and collecting larvae, demonstrating the importance of including these methods in surveys. The rare *D. lyella* occurred only in sweep samples. An additional nine species were collected only by sweeping, hand-collecting or picking aquatic immatures: *Hellyethira basilobata, H. exserta, Maydenoptila explicata, O. maculata, O. acta, Agapetus laparus, Tamasia variegata, Hydrobiosella cognata* and *Liapota lavara.* Two new Tasmanian species which were also collected only in sweep nets have recently been described by Wells (1998).

Patchiness of Species Records and Potential Seasonal Effects

There appears to be a large element of chance in the recording of many species. Twenty-one species were recorded from only a single specimen. At least two of these (*Costora seposita* and *Conoesucus fromus*) are known from larval studies to be abundant at some sites (Jackson 1991). The threatened species were very uncommon in samples. For example, only two males of *Taskiria mccubbini* were collected from about 950 caddis specimens from the site. *O. maculata* was not re-collected from a previously known site (Wedge River) but it is not possible to say whether the species no longer occurs there or whether more intensive effort is needed to find it.

It is possible that we did not sample during times of peak adult abundance of the species which were rare in samples, despite sampling being timed to coincide with previous collection dates of the threatened species (Neboiss 1977, Wells 1980). The length of adult flight period is unknown for most species, and their rareness could be a sampling artefact. Resolution of this uncertainty requires increased frequency of sampling throughout the likely adult period (spring to autumn).

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APPENDIX 1
Trichoptera species recorded in 1998–99 surveys, site-date nos. 1 to 26

Species recorded*	Site-date no. (x = record; ? = tentative identification)																									
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Hydrobiosidae																										
Apsilochorema obliquum			x	x							x					x		?	x	x						
Apsilochorema gisbum													x	x			x	x							x	
Allochorema tasmanicum																		x							x	
Ipsebiosis spicula																									x	
Ulmerochorema breve							x											x								
Ulmerochorema onychion																									x	
Ulmerochorema rubiconum			x	x	x									x												
Ulmerochorema sp.									?																	
Ethochorema secutum																									x	
Ethochorema nesydrion				x										x										x	x	
Ethochorema sp.									?																	
Taschorema asmanum											x			x	x										x	
Taschorema apobamum			x	x	x			x			x							x							x	
Taschorema viridarium	x			?		x		x							x											
Taschorema pedunculatum				?							x					x		x			x				x	
Taschorema evansi				x									x	x	x		x	x							x	
Taschorema sp.	?				?				x							?	?									
Poecilochorema sp.																										
Ptychobiosis nigrita								x			x									x					x	
Koetonga clivicola								x	x		x															
Moruya charadra	x				x																					
Moruya opora				x	x	x					x														x	
Glossosomatidae																										
Agapetus tasmanicus																										
Agapetus cralus									x																	
Agapetus laparus																										
Hydroptilidae																										
Orphninotrichia acta												x														
**Orphninotrichia maculata*																										
Hellyethira exserta																										
Hellyethira simplex														x											x	
Hellyethira multilobata														x										x	x	
Hellyethira basilobata		x																								
Hellyethira malleoforma																										
Oxyethira columba	x						x																			
Oxyethira sp.		x						x						x												
Maydenoptila explicata						x					x															
Maydenoptila cuneola																										
Maydenoptila sp.																										
Philopotamidae																										
Hydrobiosella orba																										
Hydrobiosella cerula																										
Hydrobiosella tasmanica																										
**Hydrobiosella armata*								?																		
Hydrobiosella cognata									x																	
Hydrobiosella waddama				x																						
Hydrobiosella sp.																	x	x								
Ecnomidae																										
Ecnomus tillyardi														x		x		x		x					x	x
Ecnomus cygnitus														x		x		x		x					x	
Ecnomus turgidus														x												
Ecnomina irrorata														x		x		x							x	x
Ecnomina legula														x				x							x	
Ecnomina sp. nov.																		x							x	
Polycentropodidae																										
Plectrocnemia altera													x	x				?		?					x	
Plectrocnemia caudata																										
Plectrocnemia sp.																							x			

cont.

Appendix 1 cont.

Species recorded*	Site-date no. (x = record; ? = tentative identification)																									
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Hydropsychidae																										
Smicrophylax creektona																										
Smicrophylax simplex																										
**Diplectrona lyella*										x																
Plectrotarsidae																										
Plectrotarsus sp.																		x								
Liapota lavara																										
Limnephilidae																										
Archaeophylax ochreus			?	x				x			x			x												
Archaeophylax vernalis																										
Kokiriidae																										
Taskiria austera																										
**Taskiria mccubbini*																								x		
**Taskiropsyche lacustris*																										
Oeconesidae																										
Tascuna ignota								x							x					x					
Calocidae																										
Caenota plicata																										
Tamasia variegata										x																
Helicophidae																										
Helicopha astia																										
Allocella grisea																										
Alloecella longispina				x										x				x								
Alloecella pilosa																										
Conoesucidae																										
Hampa patona																										
Costora ebenina																										
Costora ramosa															x	x										
Costora krene																x										
Costora seposita																										
Costora sp.														x												
Conoesucus fromus																										
Conoesucus nepotulus																x		x								
Conoesucus sp.						x																				
Conoesucidae sp.																										
Atriplectididae																										
Atriplectides dubius														x		x		x		x					x	x
Philorheithridae																										
Austrheithrus glymma																										
Aphilorheithrus decoratus			x										x	x	x	x					x					
Aphilorheithrus luteolus					x																					
Leptoceridae																										
Triplectides similis														x												
Triplectides bilobus											x			x		x				x					x	
Triplectides sp.																			x	x						
Notoperata sparsa																?		?							x	
Notoperata maculata								?			x			x						x					x	
Notoperata sp.																				x					x	
Lectrides varians														x											x	
Notalina fulva														x		x		x		x					?	
Notalina sp.				x		x														x					x	
Condocerus paludosus																		x							x	
Leptorussa darlingtoni														x												
Oecetis pechana																				x						
Oecetis australis														x		x		x		x					x	
Oecetis minasata														?	x				x							
Oecetis laustra														x		x		x		x					x	
Oecetis arcada													x	x				?								
Oecetis scirpicula														x		x		x		x					x	
Oecetis sp.											x							x							x	

* Threatened species.

APPENDIX 2
Trichoptera species recorded in 1998–99 surveys, site-date nos. 27 to 52

Species recorded*	Site-date no. (x = record; ? = tentative identification)																								
	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
Hydrobiosidae																										
Apsilochorema obliquum			x	x								x							x	x			x			
Apsilochorema gisbum	x	x		x	x	x																				
Allochorema tasmanicum																										x
Ipsebiosis spicula																										
Ulmerochorema breve																										
Ulmerochorema onychion																										
Ulmerochorema rubiconum						x							x													
Ulmerochorema sp.						x											x									
Ethochorema secutum																										
Ethochorema nesydrion			x	x								x			x	x					x					
Ethochorema sp.																										
Taschorema asmanum			x								x	x			x	x								x		
Taschorema apobamum		x			x	x													x							
Taschorema viridarium																										
Taschorema pedunculatum				x																						
Taschorema evansi						x			x						x	x										
Taschorema sp.						?																				x
Poecilochorema sp.																										x
Ptychobiosis nigrita						x			x																	
Koetonga clivicola				x												x									x	
Moruya charadra				x												x	x									
Moruya opora		x				x						x														
Glossosomatidae																										
Agapetus tasmanicus											x	x	x	x	x	x	x									
Agapetus cralus												x		x				x	x				x		x	
Agapetus laparus																			x							
Hydroptilidae																										
Orphninotrichia acta																										
**Orphninotrichia maculata*																									x	
Hellyethira exserta																	x									
Hellyethira simplex						x										x									x	
Hellyethira multilobata																										
Hellyethira basilobata													x													
Hellyethira malleoforma						x																				
Oxyethira columba			x	x											x		x			x	x			x		
Oxyethira sp.																							x		x	
Maydenoptila explicata											x				x		x									
Maydenoptila cuneola																x	x									
Maydenoptila sp.												x											?			
Philopotamidae																										
Hydrobiosella orba								x																		x
Hydrobiosella cerula																										x
Hydrobiosella tasmanica																						x	?			
**Hydrobiosella armata*																										
Hydrobiosella cognata																										
Hydrobiosella waddama																										
Hydrobiosella sp.				x																						x
Ecnomidae																										
Ecnomus tillyardi		x				x	x			x																
Ecnomus cygnitus																										
Ecnomus turgidus																										
Ecnomina irrorata		x				x																				
Ecnomina legula						x													x							
Ecnomina sp. nov.						x			x																	
Polycentropodidae																										
Plectrocnemia altera		?				x			x		?					x			x				x			
Plectrocnemia caudata									x							x		x	x				?			
Plectrocnemia sp.												x				x					x					

cont.

Appendix 2 cont.

Species recorded*	Site-date no. (x = record; ? = tentative identification)																								
	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
Hydropsychidae																										
Smicrophylax creektona																x	x									
Smicrophylax simplex															x											
**Diplectrona lyella*											x															
Plectrotarsidae																										
Plectrotarsus sp.																										
Liapota lavara																									x	
Limnephilidae																										
Archaeophylax ochreus											x	x				x							x		x	
Archaeophylax vernalis				x																						
Kokiriidae																										
Taskiria austera																										x
**Taskiria mccubbini*																										
**Taskiropsyche lacustris*								x																		
Oeconesidae																										
Tascuna ignota																x			x		x		x			
Calocidae																										
Caenota plicata												x				x										
Tamasia variegata																										
Helicophidae																										
Helicopha astia			x																							
Allocella grisea																x			x							
Alloecella longispina												x		x		x	x		x				x			
Alloecella pilosa			x												x											
Conoesucidae																										
Hampa patona											?															
Costora ebenina													x													
Costora ramosa													x		x			x	?							
Costora krene														x												
Costora seposita											x															
Costora sp.				x																						
Conoesucus fromus																	?									
Conoesucus nepotulus													?	x								x				
Conoesucus sp.																										
Conoesucidae sp.				x										x	?		x		x		x				x	
Atriplectididae																										
Atriplectides dubius						x																				
Philorheithridae																										
Austrheithrus glymma																x										
Aphilorheithrus decoratus		x	x	x		x			x			x			x	x		x	x	x	x		x	x	x	
Aphilorheithrus luteolus																										
Leptoceridae																										
Triplectides similis																										
Triplectides bilobus				x					x							x			?		x		x			
Triplectides sp.												x														
Notoperata sparsa																										
Notoperata maculata						x			x														x			
Notoperata sp.												x									x					
Lectrides varians																										
Notalina fulva						x																				
Notalina sp.		x				x											x									
Condocerus paludosus				x																						
Leptorussa darlingtoni																										
Oecetis pechana																										
Oecetis australis		x		x		x													x				x			
Oecetis minasata																										
Oecetis laustra																			?							
Oecetis arcada				x												x			x				x			
Oecetis scirpicula		x				x																				
Oecetis sp.									x																	
Leptoceridae sp.																							x			

* Threatened species.

EDMUNDSIOPS HICKMANI SP. NOV., *OFFADENS FRATER* (TILLYARD) NOV. COMB. AND DESCRIPTION OF THE NYMPH OF *CLOEON TASMANIAE* TILLYARD (EPHEMEROPTERA: BAETIDAE) FROM TASMANIA

by Phillip J. Suter

(with two tables and 63 text-figures)

SUTER, P.J., 2000 (31:xii): *Edmundsiops hickmani* sp. nov., *Offadens frater* (Tillyard) nov. comb. and description of the nymph of *Cloeon tasmaniae* Tillyard (Ephemeroptera: Baetidae) from Tasmania. *Pap. Proc. R. Soc. Tasm.* 134: 63–74. ISSN 0080–4703. CRC for Freshwater Ecology, c\- Department of Environmental Management and Ecology, La Trobe University Albury/Wodonga Campus, PO Box 821, Wodonga, Victoria, Australia 3689.

This describes a new species (*Edmundsiops hickmani*) of baetid mayfly (Ephemeroptera) from Tasmania, updates the earlier (1936) work by R.J. Tillyard with recognition of a new combination (*Offadens frater*) and provides the first description of the nymph of *Cloeon tasmaniae* Tillyard. *E.hickmani* and *O. frater* are common throughout southeastern Australia, whereas *C. tasmaniae* has only been recorded from Tasmania.

Key Words: Ephemeroptera, mayflies, taxonomy, *Offadens*, *Edmundsiops*, *Cloeon*, Tasmania.

INTRODUCTION

The mayflies of Tasmania have long been recognised as important aquatic insects, usually associated with trout fishing. Tillyard (1936) published his major study on Tasmanian mayflies as "The Trout-Food Insects of Tasmania". In this, Tillyard described two baetid mayflies, *Baetis frater* and *Cloeon tasmaniae*. Although Scholes (1961) refers to both these species, the nymph of *C. tasmaniae* has never been described. Following examination of the type series of *B. frater* adults and nymphs, it was clear that the nymphal series contained two species, one of which was presumably the nymph of *B. frater*. Several trips to the type locality (the Weld River east of Weldborough in northeastern Tasmania) have enabled association of both the nymphal species found in Tillyard's type series with adults. This has enabled clear identification of both stages of *B. frater* and of a previously undescribed species.

Recent publications by Lugo-Ortiz & McCafferty (1998, 1999) have changed the generic status for baetids in Australia. These publications have confirmed the views by Dean & Suter (1996) and Suter (1997) that *Baetis* does not occur in Australia. Lugo-Ortiz & McCafferty (1998, 1999) described two new genera from Australia: *Offadens*, which is consistent with Baetid Genus 1 (Dean & Suter 1996, Suter 1997), and *Edmundsiops*, a genus consistent with Baetid Genus 2 (Dean & Suter 1996, Suter 1997). In Tillyard's type series from the Weld River, both these genera were represented in the nymphal series.

It is now possible to formally recognise *Offadens frater* (Tillyard) nov. comb. in both adult and nymphal stages, and *Edmundsiops hickmani* sp. nov. is described from both life stages.

In addition, collections of *Cloeon tasmaniae* have been made from the type locality (Macquarie River at "Stewarton") and the nymphs and adults have been associated from a population in the Elizabeth River at Campbell Town. A description of the nymph of *C. tasmaniae* is provided.

MATERIALS AND METHODS

Nymphs were collected from streams by sweep net sampling using a dip net with 250 µm mesh. Flowing sections of the streams were sampled, using a kick method that disturbed the substrate and dislodged nymphs into the net held downstream of the disturbance. In pools, the net was swept through the vegetation and near bottom substrate, so that nymphs were collected. Mature nymphs were placed in rearing containers (Edmunds *et al.* 1976) which were suspended in flowing water in the stream. A single nymph was placed in each container, and they were examined twice per day until the nymph emerged. The subimago was then placed in a separate dry container until it emerged to the imago. The nymphal exuvium was placed in 75% ethanol and, when the imago emerged, it too was preserved in the sample vial with the exuvium. Additional adult material was collected by beating the riparian vegetation with a standard adult insect net with mesh of 1 mm. All material was preserved in 75% ethanol.

Additional nymphal material was made available from collections made throughout Tasmania by the Hydro Electric Commission Environmental Assessment, the Inland Fisheries Commission, the Regional Assessment Programme and the Monitoring River Health Programme.

The nymphal exuvium was dissected and then mounted on slides in polyvinyl-lactophenol mountant. The wings and legs of adults were also mounted in polyvinyl-lactophenol, and the genitalia were wet-mounted in ethanol and then maintained in a separate vial containing 75% ethanol.

Illustrations were prepared with the aid of a camera lucida attached to a Leitz compound microscope. All measurements are based on a minimum of ten nymphs and expressed in millimetres. Type material is deposited in the Australian National Insect Collection (ANIC). The Monitoring River Health Programme material is deposited in the Tasmanian Museum, Hobart, and all the Victorian material is deposited in the Museum of Victoria.

Collectors abbreviations are: MV = Museum of Victoria Survey Department; LTCS = La Trobe Catchment Survey,

Museum of Victoria; TRS = Thomson River Survey, Museum of Victoria; Vic EPA = Victorian Environment Protection Authority; HEC = Hydro Electric Commission [Tasmania] Environmental Assessment; RAP = Regional Assessment Study [Tasmania]; JB = J. Blyth; PJS = P.J. Suter; PG = P. Goonan; MS = M. Suter; GS = G. Slattery; DO = D. Oldmeadow; MN = M. Nelson; MP = M. Pearson; BK = B. Knott; PH = Pierre Horwitz; BC = B. Chessman; SC = S. Chilcott.

Offadens frater (Tillyard) nov. comb.

Baetis frater Tillyard, 1936: 50 [Type species]
Baetis frater Scholes 1961: 36
Baetidae Genus 1 sp8 Suter 1997: 18

Type material

Holotype male imago: a small creek near Weldborough in northeastern Tasmania, R.J. Tillyard, British Museum of Natural History, examined. Nymphs: as for holotype, contained in paratype series, examined.

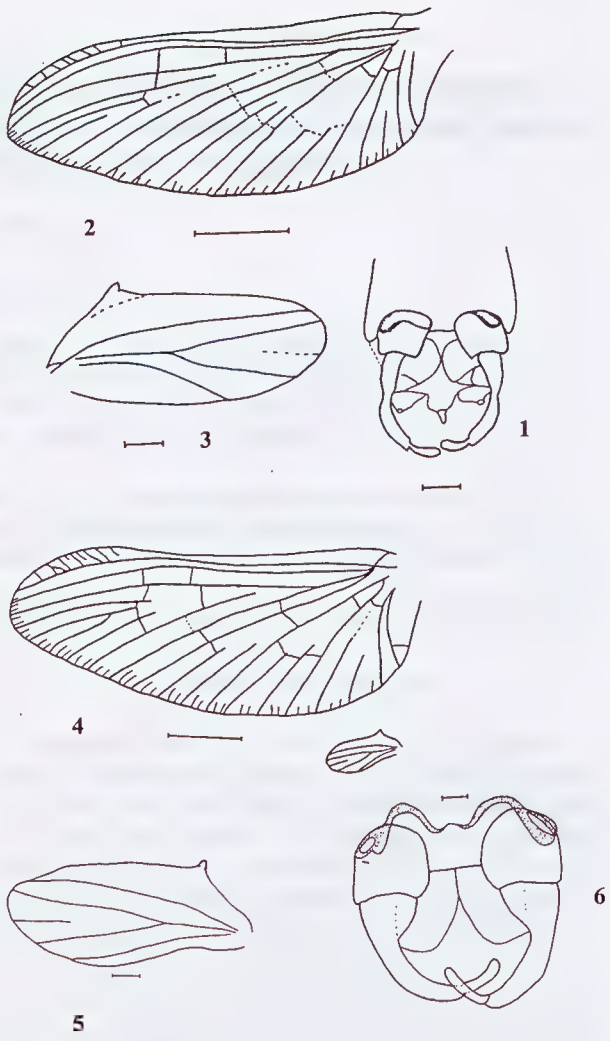
Additional material examined

Tasmania: 4 nymphs, Barrow Creek on Tasman Highway, 8.ii.1995, 41°20'S 147°23'E, PJS and PG; 2 nymphs, Break O'Day River east of Fingal, 10.ii.1995, 41°36'S 148°03'E, PJS and PG; 8 nymphs, Brid River on Tasman Highway, 8.ii.1995, 41°12'S 147°29'E, PJS and PG; 9 nymphs, Fern Tree Glen Creek near Falmouth, 10.ii.1995, 41°31'S 148°14'E, PJS and PG; 5 male imagos, 30 nymphs, George River at Goshen, 9.ii.1995, 41°07'S 148°05'E, PJS and PG; 24 nymphs, Great Musselroe River on road to Pioneer, 9.ii.1995, 41°05'S 148°03'E, PJS and PG; 1 nymph, North George River at Willows Rd, 9.ii.1995, 41°16'S 147°59'E, PJS and PG; 2 nymphs, Macquarie River at "Stewarton", 12.iii.1994, 41°49'S 147°15'E, PJS; 2 nymphs on slides, Powers Rivulet, 7.iii.1994, 41°07'S 148°09'E, PJS and MS; 12 nymphs, Ringarooma River at Pioneer, 9.ii.1995, 41°05'S 147°57'E, PJS and PG; 2 nymphs on slides, Ringarooma River at Moorina, 7.iii.1994, 41°08'S 147°52'E, PJS and MS; 1 nymph, Seven Time Creek on Tasman Highway, 8.ii.1995, 41°21'S 147°22'E, PJS and PG; 2 nymphs on slides, St Pauls River at Avoca, 9.iii.1994, 41°47'S 147°29'E, PJS; 1 nymph, St Patricks River at Nunamara, 8.ii.1995, 41°23'S 147°18'E, PJS and PG; 4 nymphs, Weld River east of Weldborough, 10.iii.1994, 41°12'S 147°55'E, PJS, 8.ii.1995, PJS and PG; *Victoria*: 1 nymph, Murray River at Bunroy Track, 5.iii.1994, 36°40'S 148°02'E, Vic. EPA. *South Australia:* 10 nymphs, Eight Mile Creek near Pt Macdonald, 15.i.1977, 38°03'S 140°48'E, PJS.

Description

Imago

The imago was fully described by Tillyard (1936) but the genitalia were not illustrated. The following is added to the original description based on the holotype and fresh specimens: forceps three-segmented, basal segment broad and rectangular, second segment long and slender, distal segment long and slender (fig.1); forelegs buff, not banded, segment ratios 1.00 : 1.89 : 0.09 : 0.80 : 0.72: 0.72 : 0.07 (0.9 mm); mid and hind leg ratios 1.00 : 0.77 : – : 1.50 : 0.12 : 0.006 : 0.12 (0.65 mm); abdomen buff, translucent except for segments 7–10 which are brown. This is the first associated imago of the genus *Offadens*. The generic



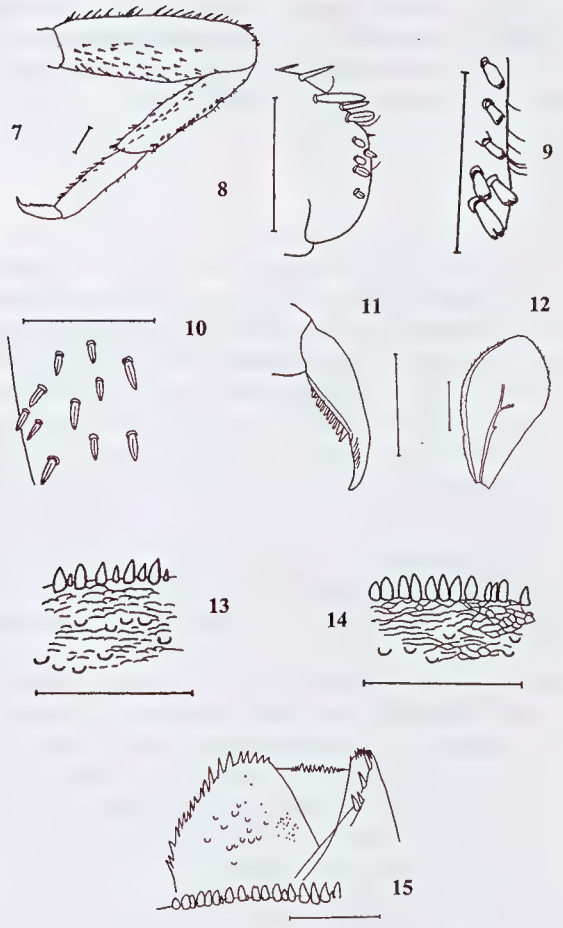
FIGS 1–6. Adults of Offadens frater *and* Edmundsiops hickmani. Offadens frater *male imago: (1) Genitalia, ventral; (2) Forewing; (3) Hind wing, enlarged.* Edmundsiops hickmani *male imago; (4) Fore and hind wing; (5) Hind wing, enlarged; (6) Genitalia, ventral. Scales: figs 1, 3, 5, 6 – bar = 0.1 mm; figs 2, 4 – bar = 1 mm.*

characteristics of this genus are: male compound eye turbinate, separate; two pairs of wings; forewings (fig. 2) with paired intercalaries extending from the Sc to the Cu sectors; ICuA connected basally with both CuA and CuP; hindwing with strong costal process (fig. 3); genitalia three segmented; cerci present, appendix dorsalis absent; foretarsus with 5 segments, mid and hind tarsi with only 4 segments.

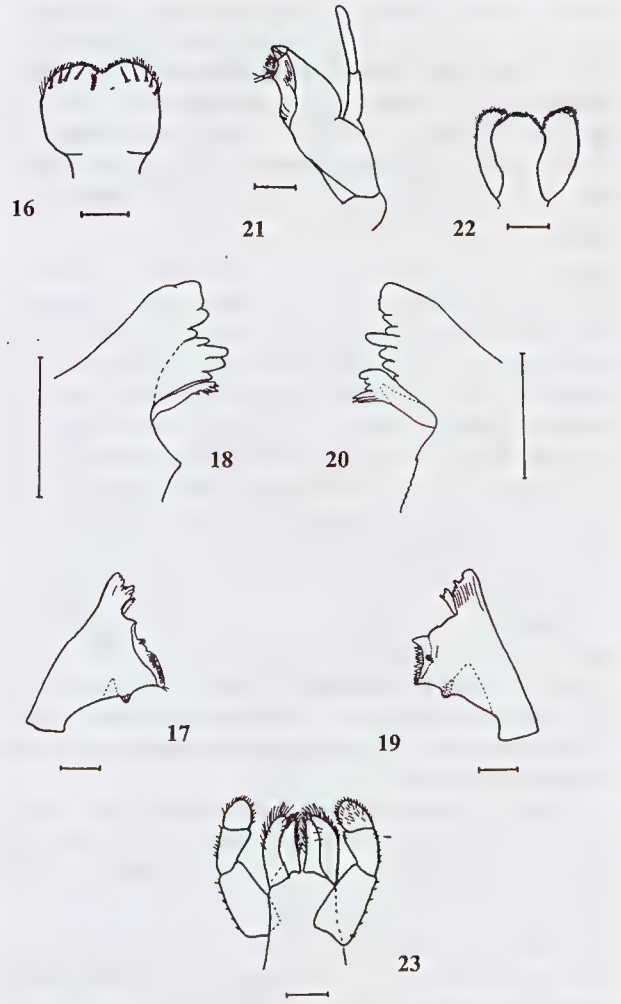
Mature nymph

Body length 3.8–5.2 mm, cerci 2.0–2.3 mm, terminal filament 1.3–1.7 mm.

Pronotum narrower than head, dark grey. Mesothorax dark with light markings; metathorax with hind wing pads present in mature nymphs (fig. 61, see later, p. 71). Metathorax white. Fore legs with margins of femora with a fringe of 21–28 sharp spine setae (fig. 7), apex with short, blunt setules (fig. 8), mesial margin with numerous divided spine setae (fig. 9); fore tibiae with outer margin lined with 6–14 short blunt spine setae and few hairs (fig. 10), inner margin with 7–11 spine setae; outer margin of tarsi without



FIGS 7–15. Offadens frater *nymph: (7) Fore leg; (8) Apex of fore femur; (9) Setae along margin of fore tibia; (10) Spines on mesial margin of fore femur; (11) Fore tarsal claw; (12) 4th gill; (13) Spines on posterior margin of 5th abdominal tergite; (14) Spines on posterior margin of 8th abdominal sternite; (15) Left paraproct, ventral. Scale: bars = 0.1 mm.*



FIGS 16–23. Offadens frater *nymph: (16) Labrum; (17) Right mandible; (18) Enlarged incisors and prostheca of right mandible; (19) Left mandible; (20) Enlarged incisors and prostheca of left mandible; (21) Maxilla; (22) Hypopharynx; (23) Labium, dorsal (left of midline) and ventral (right of midline). Scale: bars = 0.1 mm.*

setae, but occasional short hairs present; inner margin with 9–11 short spine setae, tarsal claws with 11–13 proximal teeth (fig. 11). Middle legs with margins of femora with a fringe of 20–34 setae and few hairs; mid tibiae with outer margins with 8–15 short spine setae, inner margins with 4–11 spine setae; outer margins of tarsi with 0–7 short spine setae, inner with 8–13 spine setae; tarsal claws with 10–13 proximal teeth. Hind legs with margins of femora with a fringe of 20–27 sharp spine setae; hind tibiae with outer margin lined with 6–14 short blunt spine setae, inner margin with 5–12 spine setae; outer margin of tarsi 1–2 setae, and occasional short hairs present, inner margin with 9–11 spine setae; tarsal claws with 9–11 proximal teeth.

Ratios of leg segments:

fore leg	1.00 : 0.71 : 0.66 (0.60 mm);
middle leg	1.00 : 0.68 : 0.59 (0.63 mm);
hind leg	1.00 : 0.62 : 0.56 (0.67 mm).

Femur length to width ratios: fore leg 2.69 (2.30–2.94), middle leg 2.91 (2.61–3.14), hind leg 3.23 (2.91–3.75).

Abdominal segments 1–7 with single ovate plate-like gills with serrated and ciliated margins (fig. 12). Distinct colour pattern with first abdominal segment white, second and third dark, fourth with a light globular pattern, fifth tergite white, sixth and seventh dark, eighth white, ninth dark and tenth white (fig. 61, p. 71). Postero-lateral margins lacking spines. Posterior margins of tergites with distinct sharp teeth and rugose surface with scale scars present (fig. 13). Posterior margins of sternites with larger teeth (fig. 14). Paraprocts with >20 well-developed spines on inner and apical margins, few scales present (fig. 15).

Labrum ovoid with a deep concavity in centre of the anterior margin, which is lined with fine setae, row of spine setae posterior to margin (fig. 16). Mandibles lack marginal setae, incisors fused with outer group blunt with "shearing" surface, inner incisors toothed. Right mandible (fig. 17) with outer incisors blunt with two inner teeth, inner incisors with 4 apical teeth, prostheca single with row of short spines apically (fig. 18), tubercle between incisors and molars well developed. Left mandible (fig. 19) with outer incisors blunt apically with 2 inner teeth, inner incisors with 1 large tooth and three smaller teeth, prostheca robust, margin between incisors and molars slightly serrated (fig. 20). Maxillae (fig. 21) with 4 blunt teeth at crown of galeo-laciniae, row of 3–4 fine simple setae near medial

hump, palp 2-segmented, apical segment longer than basal segment, palpi longer than galeo-lacinia, segment ratios 1.00 : 1.84 (0.09 mm). Hypopharynx as in figure 22. Labium (fig. 23) with glossae and paraglossae curved and pointed, labial palpi with 3 segments, mesial margin of second segment slightly produced; apical segment ovoid, proximal segment of labial palp 1.54x longer than broad, segment ratio 1.00 : 1.54 : 0.52 (0.16 mm).

Notes on *Offadens*

Offadens frater (Tillyard) was described as *Baetis frater* by Tillyard in 1936 from a small stream (the Weld River) near Weldborough in northeastern Tasmania. The adult and nymphs were described but, on examination of the holotype imago and paratype nymphs, it was clear that Tillyard had included two species of nymph in the paratype series. It was unclear from Tillyard's nymphal description which of the two nymphs he had described. Collections from the type locality indicated that both species are still common in the Weld River near Weldborough and, after numerous attempts to rear the two species, it has been established that the nymph which, when reared, has an adult identical to the holotype is consistent with *Offadens*, whereas the other species is consistent with Baetidae Genus 2 MV sp3 (Suter 1997) and here is described as a new species of *Edmundsiops*. Therefore, *B. frater* Tillyard is now recognised as *O. frater* (Tillyard) comb. nov.

Offadens frater can be distinguished from all other species in the genus by the following combination of characters: mandibles with outer incisors blunt, shearing surfaces, prostheca of right mandibles single with row of short spines apically; femora of fore leg with short spine setal fringe, apex of femora with short, divided setules; mesial margin of femora with numerous divided setae, tibiae lined with short, blunt, divided setules, but without a large apical setule, tarsi with less than five setae on outer margin, abdominal colour pattern with segments 1, 5, 8 and 10 white, 2–4, 6, 7 and 9 dark, strongly contrasting with the lighter segments.

This small species is common in riffles throughout northeastern Tasmania and occurs in Victoria and southeastern South Australia. It is likely this species is more widespread than recorded here but, because of its small size, it is often overlooked as a juvenile of a larger species in Monitoring River Health Initiative sampling, when samples are sorted in the field. Suter (1997) referred to this species as Baetidae Genus 1 sp8 and recognised that it included the Victorian Environment Protection Authority voucher species Vic EPA sp 8 and Vic EPA sp 11.

Edmundsiops hickmani sp. nov.

Baetis frater Tillyard, 1936: 50 (incorrect designation in nymphal type series)
Genus 2 MV sp 3 Suter, 1997: 20.

Type material

Holotype nymph on slides, Weld River near Weldborough, 6.iii.1994, 41°12'S 147°55'E, PJS; Paratype Material: 3 nymphs on slides, Weld River near Weldborough, 6.iii.1994, 41°12'S 147°55'E, PJS, 3 nymphs, 8.ii.1995, PJS and PG; 5 male imagos (1 on slides), Rose River at gauge station, 10.xi.1998, 36°49'S 146°34'E, MP and PJS.

Etymology

The specific epithet *hickmani* is in honour of Dr John L. Hickman who fostered taxonomic studies at the University of Tasmania and whose friendship and enthusiasm for the diversity of life has been an inspiration to me.

Material examined

Tasmania: 1 nymph, Andersons Creek at Tattersalls Rd,26.vi.1996, 41°11'S 146°46'E, RAP; 13 nymphs, Apsley River, 5.vi.1996, 41°49'S 148°09'E, RAP; 6 nymphs, Arm River at Mersey River Junction, 29.ii.1996, 41°42'S 146°13'E, HEC; 2 nymphs, Back River at Stonehurst, 21.vi.1996, 42°31'S 147°47'E, RAP; 11 nymphs, Blackman River at Mike Howes Marsh, 4.vi.1996, 42°14'S 147°15'E, RAP; 30 nymphs, Blackman River at Old Tier Rd, 4.vi.1996, 42°10'S 147°21'E, RAP; 8 nymphs, Brid River on Tasman Highway, 8.ii.1995, 41°12'S 147°29'E, PJS and PG; 11 nymphs, Brumbys Creek upstream Palmers Rivulet on Blackwood Rd, 24.iv.1996, 41°45'S 147°01'E, HEC; 10 nymphs, Brumbys Creek at Saundridge Rd, 24.iv.1996, 41°45'S 146°59'E, HEC; 3 nymphs, Buffalo Brook at Bonneys Plain, 6.vi.1996, 41°45'S 147°38'E, RAP; 28 nymphs, Camden Rivulet, 27.vi.1996, 41°19'S 147°28'E, RAP; 1 nymph, Clarence River at Lyell Highway, 10.vii.1996, 42°08'S 146°20'E, RAP; 7 nymphs, Clyde River at Black Snake Rd Bridge, 25.iv.1996, 42°11'S 147°00'E, HEC; 19 nymphs, Cooke Creek, 8.v.1996, 43°12'S 146°38'E, RAP; 6 nymphs, Coquet Creek 4 km northeast of Nunamara, 27.vi.1996, 41°22'S 147°20'E, RAP, 14 nymphs, 1 subimago, 8.ii.1995 PJS and PG; 11 nymphs, Cygnet River at McKays Rd, 7.vi.1996, 41°57'S 147°53'E, RAP; 7 nymphs, Dans Rivulet near Mathinna, 10.ii.1995, 41°26'S 147°52'E, PJS and PG; 15 nymphs, Derwent River at Wayatinah, 10.v.1996, 42°24'S 146°29'E, HEC; 17 nymphs, Dorset River at Ringarooma, 10.ii.1995, 41°16'S 147°47'E, PJS and PG; 9 nymphs, Douglas River at Tasman Highway, 5.vi.1996, 41°47'S 148°15'E, RAP, 5 nymphs on slides, 17.i.1990, SC; 1 nymph, Dukes River at Dukes Marsh, 6.vi.1996, 41°43'S 148°08'E, RAP; 1 nymph, Fern Tree Glen Creek near Falmouth, 10.ii.1995, 41°31'S 148°14'E, PJS and PG; 18 nymphs, Fingal Rivulet at Fingal, 6.vi.1996, 41°39'S 148°00'E, RAP; 1 nymph, Fisher Creek downstream of power station, 1.iv.1996, 41°41'S 146°46'E, HEC; 8 nymphs, 10.ii.1995, PJS and PG; 1 nymph, Ford River at Roses Tier Rd, 21.vi.1996, 41°28'S 147°38'E, RAP; 1 nymph, Forth River downstream of Wolfram Mine, 30.iv.1996, 41°42'S 146°06'E, HEC; 2 nymphs on slides, Franklin Rivulet, 13.x.1994, 41°17'S 146°36'E, DO and MN; 7 nymphs, Franklin River downstream of Blackmans Bend, 14.vi.1996, 42°31'S, 145°45'E, HEC; 4 nymphs, Great Musselroe River at Tebrakunna Rd, 19.vi.1996, 41°05'S 148°04'E, RAP; 1 nymph, Great Musselroe River at New England Rd, 41°09S 148°04'E, RAP; 3 nymphs on slides, Groom River, 7.iii.1994, 41°06'S 148°05'E, PJS; 4 nymphs, Hatfield River at Highway, 2.vii.1996, 41°32'S 145°39'E, RAP; 6 nymphs, Hellyer River at Murchison Highway, 2.vii.1996, 41°16'S 145°37'E, RAP; 4 nymphs, Huon River at Cracroft Junction, 13.vi.1996, 43°07'S 146°30'E, HEC; 1 nymph on slide, Inglis River on Jessie Rd, 19.x.1994, 41°06'S 145°35'E, DO and MN; 4 nymphs, Iris River at Cradle Rd, 5.vii.1996, 41°32'S 145°59'E, RAP;

4 nymphs, Jackeys Creek at Jackeys Marsh, 24.vi.1996, 41°40'S 146°39'E, RAP; 1 nymph on slide, Jane River tributary at Lightning Plains, 29.i.1989, 42°21'S 145°52'E, PH and BK; 2 nymphs, James River upstream L. Augusta, 2.v.1996, 41°51'S 146°29'E, HEC; 9 nymphs, Judds Creek upstream Judbury, 27.v.1996, 42°59'S 146°56' E, RAP; 8 nymphs, Kermandie River, 30.v.1996, 43°11'S 146°52'E, RAP; 3 nymphs on slides, Lachlan River at New Norfolk, 11.iii.1994, 42°46'S 147°00'E, PJS; 10 nymphs, Lake River at Den, 25.iv.1996, 41°58'S 147°04'E, HEC; 2 nymphs, Little Den Creek, 17.vi.1996, 42°46'S 147°08'E, RAP; 6 nymphs, Little Denison River at McDougalls Rd, 27.v.1996, 42°59'S 146°48'E, RAP; 1 nymph, Little Pine River downstream Little Pine Lagoon, 25.v.1996, 42°01'S 146°35'E, HEC; 4 nymphs, Lost Falls Creek, 18.vi.1996, 42°03'S 147°53'E, RAP; 1 nymph, Mackintosh Creek at Lake Mackintosh, 9.vii.1996, 41°38'S 145°45'E, RAP; 27 nymphs, Maclaines Creek upstream of Salmon Creek, 7.vi.1996, 42°29'S 147°51'E, RAP; 11 nymphs, Margison Creek at St Marys, 10.ii.1995, 41°35'S 148°11'E, PJS and PG; 1 nymph on slides, Meander River upstream of Deloraine, 13.x.1994, 41°32'S 146°38'E, DO and MN; 33 nymphs, Memory Creek at Upper Esk Rd, 20.vi.1996, 41°24'S 147°42'E, RAP; 1 nymph on slide, Mersey River upstream of Union Bridge, 19.x.1994, 41°32'S 146°27'E, DO and MN; 1 nymph, Mersey River downstream Rowallan Dam, 1.iv.1996, 41°42'S 146°14'E, HEC; 2 nymphs, Mersey River upstream Soda Creek 29.iv.1996, 41°33'S 146°14'E, HEC; 6 nymphs, Mersey River upstream Sales Rivulet, 24.iv.1996, 41°43'S 146°36'E, HEC; 4 nymphs on slides, Minnow Creek upstream Lower Beulah, 16.x.1994, 41°28'S 146°20'E, DO and MN; 17 nymphs, Mountain River, 27.v.1996, 42°57'S 147°07'E, RAP; 1 nymph, Mt Riveaux Creek, 31.v.1996, 43°08'S 146°41'E, RAP; 12 nymphs, Musselboro Creek, 20.vi.1996, 41°27'S 147°26'E, RAP; 3 nymphs on slides, North George River, 7.iii.1994, 41°06'S 147°59'E, PJS and MS; 11 nymphs, Nicholls Rivulet, 11.vi.1996, 43°07'S 147°19'E, RAP; 14 nymphs, Nile River at English Town Rd, 7.vi.1996, 41°34'S 147°29'E, RAP; 5 nymphs, Nive River upstream Pine Tier Lagoon, 2.v.1996, 42°02'S 146°28'E, HEC; 5 nymphs, Nive River upstream Tarraleah, 10.v.1996, 42°17'S 146°26'E, HEC; 1 nymph, Nive River downstream Pine Tier Lagoon, 10.v.1996, 42°09'S 146°29'E, HEC; 39 nymphs, North George River at Willows Rd, 9.ii.1995, 41°16'S 147°59'E, PJS and PG, 3 nymphs on slides, 7.iii.1994, PJS; 2 nymphs, North Creek, 30.v.1996, 43°17'S 146°53'E, RAP; 23 nymphs, O'Connors Rivulet, 5.vi.1996, 42°06'S 147°59'E, HEC; 9 nymphs, Ouse River on Marlborough Highway, 3.v.1996, 41°59'S 146°38'E, HEC; 4 nymphs, Peak Rivulet, 31.v.1996, 43°19'S 146°53'E, RAP; 10 nymphs, Pelverata Creek, 27.v.1996, 43°03'S 146°06'E, RAP; 13 nymphs, Pine Ck upstream Pine Tier Lagoon, 2.v.1996, 42°04'S 146°29'E, HEC; 35 nymphs, Plenty River upstream of Feilton, 30.v.1996, 42°49'S 146°56'E, RAP; 15 nymphs, Plenty River upstream of Stony Creek, 30.v.1996, 42°52' 146°51'E, RAP; 7 nymphs, Plumbers Creek 27.v.1996, 43°07'S 147°46'E, HEC; 2 nymphs on slides, Powers Rivulet, 7.iii.1994, 41°07'S 148°09'E, PJS and MS; 1 nymph, Quamby Brook at Osmaston Rd, 25.vi.1996, 41°34'S 146°46'E, RAP; 24 nymphs, Ransom Creek on Terrys Hill Rd, 9.ii.1995, 41°15'S 148°04'E, PJS and PG; 4 nymphs, Ringarooma River at Pioneer, 9.ii.1995, 41°05'S 147°57'E, PJS and PG; 13 nymphs, Ringarooma River at Maurice Rd, 20.vi.1996, 41°18'S 147°41'E, RAP; 1 nymph on slide, Ringarooma River at Moorina 7.iii.1994, PJS and MS; 6 nymphs, Russell River at Russell Pimple, 11.vi.1996, 42°57'S 146°48'E, RAP; 10 nymphs, Sandspit River at Ringrove, 17.vi.1996, 42°39'S 147°54'E, RAP; 7 nymphs, Scamander River at Hogans Rd, 4.vi.1996, 41°04'S 148°06'E, RAP; 13 nymphs, Scamander River at Upper Scamander, 4.vi.1996, 41°07'S 148°20'E RAP; 5 nymphs, Serpentine Rivulet at Malborough Highway, 10.vi.1996, 42°08'S 146°30'E, RAP; 11 nymphs, Seven Time Creek on Tasman Highway, 8.ii.1995, 41°21'S 147°22'E, PJS and PG; 4 nymphs, Simmonds Creek at Fortescue Bay Rd, 27.v.1996, 43°07'S 147°54'E, RAP; 9 nymphs, Snowy Creek at Dens Marsh Creek, 7.vi.1996, 41°56'S 147°50'E, RAP; 60 nymphs, South Esk River at Griffin Rd Picnic Area, 10.ii.1995, 41°28'S 147°50'E, PJS and PG; 11 nymphs, South George River Intake Bridge, 9.ii.1995, 41°19'S 147°57'E, PJS and PG; 11 nymphs, South Styx River, 3.v.1996, 42°50'S 146°37'E, RAP; 13 nymphs, Southwell River, 8.vii.1996, 41°04'S 145°44'E, RAP; 18 nymphs, St Pauls River at Valley Rd, 6.vi.1996, 41°42'S 148°06'E, RAP; 14 nymphs, Stitt River upstream of Rosebery, 10.vii.1996, 41°49'S 145°32'E, RAP; 9 nymphs, Stony Creek, 30.v.1996, 42°52'S 146°59'S, RAP; 19 nymphs, Styx River on Cataract Rd, 31.v.1996, 42°47'S 146°46'E, RAP; 30 nymphs, Styx River at Styx Rd, 31.v.1996, 42°43'S 146°37'E, RAP; 16 nymphs, Styx River south of Karanja, 25.v.1996, 42°44'S 146°50'E, RAP; 4 nymphs, Swan River upstream of Hardings Falls, 5.vi.1996, 41°50'S 148°06'E, RAP; 7 nymphs, Sweets Creek at Mathinna Plains Rd, 20.vi.1996, 41°24'S 147°44'E, RAP; 5 nymphs, Tims Creek at Tyne Rd, 7.vi.1996 41°32'S 147°47'E, RAP; 12 nymphs, Tom Thumb Creek at Maurice Rd, 20.vi.1996, 41°19'S 147°41'E, RAP; 8 nymphs, Tower Rivulet at Rossarden Rd, 6.vi.1996, 41°37'S 147°52'E, RAP; 6 nymphs, Tyenna River upstream Maydena, 9.v.1996, 42°46'S 146°37'E, RAP; 60 nymphs, Tyenna River at Westerway, 11.iii.1994, 42°39'S 146°49'E, PJS; 28 nymphs, Wandle River at Murchison Highway, 2.vii.1996, 41°22'S 145°35'E, RAP; 13 nymphs, Wardlaws Creek at Chain of Lagoons, 5.vi.1996, 41°41'S 148°17'E, RAP; 7 nymphs, Weavers Creek, 27.vi.1996, 41°28'S 147°23'E, RAP; 5 nymphs, Weld River near Snake Rd, 13.vi.1996, 42°57'S 146°34'E, RAP; 1 nymph on slide, Weld River at Moorina, 5.x.1994, 41°08'S 147°53'E, DO and MN; 15 nymphs, Westons Rivulet at Saundridge Rd, 24.iv.1996, 41°46'S 147°59'E, HEC; 2 nymphs on slides, Wilmot River on Spellmans Rd, 13.x.1994, 41°21'S 146°10'E, DO and MN. *Victoria*: 5 nymphs on slides, Cobungra River at Angler's Rest, 1.x.1982, 37°00'S 147°30'E, MV; 6 nymphs, Cudgewa Creek at Lucyvale, 21.xi.1996, 36°17'S 147°37'E, PJS and GS; 4 nymphs on slides, Hawthorn Creek S15, 12.viii.1979, 37°58'S 146°06'E, LTCS; 8 nymphs on slides, Little Snowy Creek, 30.ix.1982, 36°30'S 147°14'E, JB; 5 nymphs on slides, Mitta Mitta River, Glenvalley on Omeo Highway, 30.ix.1982, 36°59'S 147°31'E, JB; 105 nymphs, Rose River at gauge station, 26.viii.1998, 15.ix.1998, 10.xi.1998, 8.xii.1998, 21.xii.1998, 5.i.1999, 19.i.1999, 10.i.1999, 5.ii.1999, 36°49'S 146°34'E, MP; 156 nymphs, Rose River, 13.x.1998, 10.xi.1998, 21.xi.1998, 8.xii.1998, 21.xii.1998, 5.i.1999, 19.i.1999, 36°52'S 146°33'E, MP; 111 nymphs, Rose River at Bennies, 8.xii.1998, 21.xii.1998, 5.i.1999, 19.i.1999, 5.ii.1999, 36°57'S 146°32'E, MP; 164 nymphs Rose River, Wabonga Plateau National Park, 8.xii.1998, 21.xii.1998,

5.i.1999, 36°58'S 146°31'E, MP; 10 nymphs on slides, Snowy Creek S7, 30.ix.1982, 36°17'S 147°25'E, JB; 5 nymphs on slides, Thomson River T26, 30.xii.1976, 38°03'S 146°59'E, TRS; 3 nymphs on slides, Thomson River T22, 1.xii.1976, 37°59'S 146°38'E, TRS; 5 nymphs on slides, Western Tyers River Christmas Creek Rd, 09.v.1979, 37°53'S 146°15'E, LTCS. *NSW*: 3 nymphs on slides, Woodford Creek near Mt Twiss, 2.xii.1992, 33°44'S 150°09'E, BC.

Description

Male imago

Body Length 4.4–5.6 mm, cerci 11–13 mm, terminal filament absent.

Body brown, abdomen transparent, light brown, segments 8-10 cream. Antennae short 0.6 mm; turbinate eyes separate, light brown dorsally, cream laterally. Legs cream no banding, first tarsal segment (T_1) partially fused in fore leg, T_1 and T_2 fused with tibiae in mid and hind legs.

Ratio of leg segments:
fore leg 1.00 : 1.68 : 0.06 : 0.65 : 0.60 : 0.35 : 0.16 (1.1 mm); mid and hind leg 1.00 : 1.13 : – : – : 0.12 : 0.08 : 0.21 (0.77 mm).

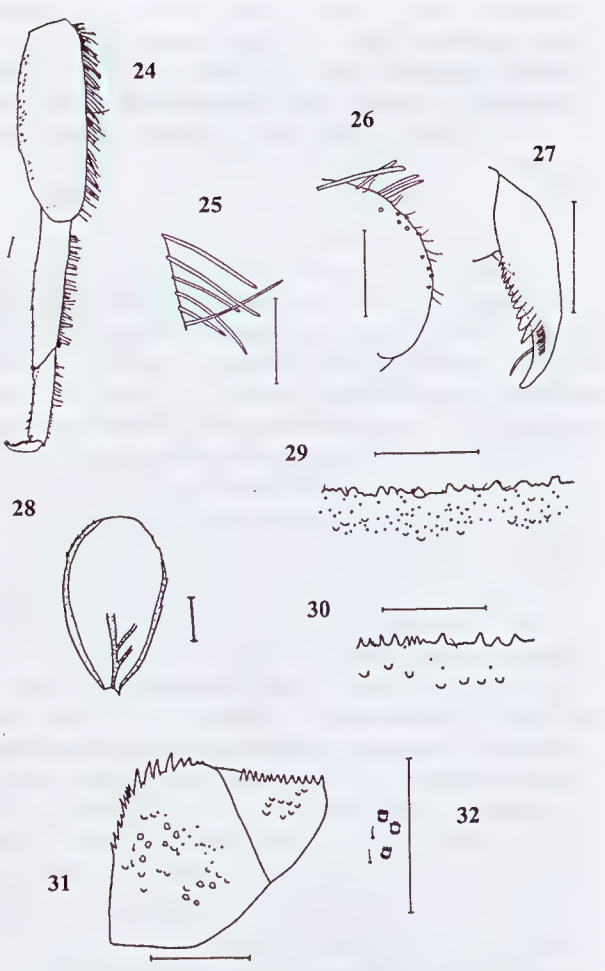
Wings hyaline, fore wing 5.0–5.7 mm long, 2.5x longer than wide, pterostigma with 7–10 cross veins, no cross veins in proximal region of costal sector, cross veins absent in subcostal sector (fig. 4). Hind wing 1.0–1.7 mm long with costal projection (fig. 5).

Cerci cream without any coloration. Genitalia with three-segmented forceps, proximal segment long approx. 1/3 length of second segment which is broad basally, narrows at 1/3 length, basal sclerite of subgenital plate concave medially (fig. 6).

Mature nymph

Body length 4.5–8.0 mm, cerci 1.4–4.9 mm, terminal filament 1.1–3.5 mm.

Pronotum narrower than head, brown along medial line. Mesothorax brown with light markings; metathorax brown, with hind wing pads present in mature nymphs. Legs buff with joints tinged dark brown, apex of tarsus and claws brown. Fore legs (fig. 24) with margins of femora with a dense fringe of 57–108 long, blunt setae (fig. 25), apex lacking spine setae, but few broad scales and hairs present, femoral extension rugose (fig. 26), mesial margin with few short spine setae; fore tibiae with outer margin lined with 16–45 long, blunt setae and numerous fine hairs, inner margin with 7–20 spine setae; outer margin of tarsi with 6–21 long, blunt setae, numerous hairs present; inner margin with 5–10 short spine setae, tarsal claws (fig. 27) with 6–13 proximal teeth and a subapical setule. Middle legs with margins of femora with a fringe of 41–96 long, blunt setae and numerous hairs; mid tibiae with outer margins with 22–49 long, blunt setae, inner margins with 9–18 spine setae and numerous hairs; outer margins of tarsi with 7–16 long, blunt setae and numerous hairs, inner with 5–8 spine setae; tarsal claws with 7–10 proximal teeth and a subapical setule. Hind legs with margins of femora with a fringe of 36–82 long, blunt setae; hind tibiae with outer margin lined with 19–46 long blunt setae and numerous hairs, inner margin with 7–18 spine setae; outer margin of tarsi with 4–17 long, blunt setae, and numerous hairs present, inner margin with 5–9 spine setae; tarsal claws with 6–12 proximal teeth and a subapical setule.



FIGS 24–32. Edmundsiops hickmani *nymph: (24) Fore leg; (25) Foreleg femoral setae; (26) Apex of fore femur; (27) Fore tarsal claw; (28) 4th gill; (29) Spines on posterior margin of 5th abdominal tergite; (30) Spines on posterior margin of 8th abdominal sternite; (31) Left paraproct, ventral; (32) Enlarged scales on paraprocts. Scale: bars = 0.1 mm.*

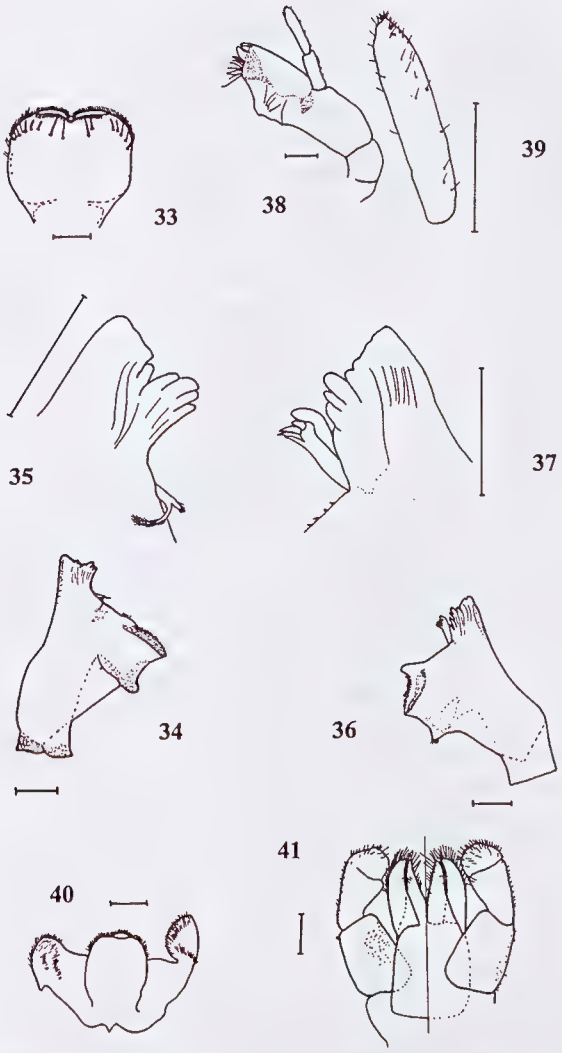
Ratios of leg segments:

fore leg	1.00:0.80:0.51 (1.09 mm);
middle leg	1.00:0.78:0.44 (1.14 mm);
hind leg	1.00:0.68:0.43 (1.12 mm).

Femur length to width ratios: fore leg 2.76 (2.28–3.53), middle leg 3.04 (2.35–3.73), hind leg 3.08 (2.39–3.74).

Abdominal segments 1–7 with single ovate plate-like gills with serrated and ciliated margins (fig. 28). Lacks a distinct colour pattern with all segments with varying patches of brown, ninth segment uniform brown, tenth segment white (fig. 62). Postero-lateral margins lacking spines. Posterior margins of tergites with blunt irregularly spaced teeth, surface with numerous hair scars and scale scars present (fig. 29). Posterior margins of sternites with larger sharp teeth and numerous hair scars and scale scars present (fig 30). Paraprocts (fig. 31) with 9–15 well developed spines on inner and apical margins, few hair scars and scale scars present, scales rectangular and fringed apically (fig. 32).

Labrum (fig. 33) ovoid with a shallow concavity in centre of the anterior margin, which is lined with fine pinnate setae, and laterally with long fringed setae; dorsally



FIGS 33–41. Edmundsiops hickmani *nymph: (33) Labrum; (34) Right mandible; (35) Enlarged incisors and prostheca of right mandible; (36) Left mandible; (37) Enlarged incisors and prostheca of left mandible; (38) Maxilla; (39) Enlarged terminal segment of maxillary palp; (40) Hypopharynx; (41) Labium, dorsal (left of midline) and ventral (right of midline). Scale: bars = 0.1 mm.*

with row of 7–8 submedial spine setae on either side of midline. Mandibles lack marginal setae, incisors fused with outer group blunt with "shearing" surface, inner incisors toothed. Right mandible (fig. 34) with outer incisors blunt with two inner teeth, inner incisors with 4 apical teeth, prostheca bifid (fig. 35), margin between incisors and molars smooth with tuft of short bristles near molars. Left mandible (fig. 36) with outer incisors blunt apically with 2 inner teeth, inner incisors with 1 large tooth and three smaller teeth, prostheca robust (fig. 37), margin between incisors and molars serrated. Maxilla (fig. 38): palp short, 2-segmented, apical segment longer than basal segment, apically with 3 small spines (fig. 39); palpi approximately equal to galeo-lacinia length, segment ratios 1.00:1.21 (0.13 mm). Hypopharynx as in figure 40. Labium (fig. 41) with glossae and paraglossae curved and pointed, labial palpi with 3 segments, mesial margin of second segment slightly produced; apical segment ovoid, proximal segment of labial palp 1.45x longer than broad, segment ratio 1.00 : 0.81 : 0.43 (0.19 mm).

Notes on *Edmundsiops*

Edmundsiops hickmani was the second species found in Tillyard's nymphal paratype series in the British Museum of Natural History. This is the second species recognised in the genus *Edmundsiops* and can be distinguished from all other species by the following characteristics in the nymph: legs with margins of femora, tibiae and tarsi with a fringe of long, blunt, robust setae (visible in immature specimens just as thoracic wing pads begin development); abdominal colour pattern indistinct, all segments with varying patches of brown, ninth segment uniform brown, tenth segment white; mandibles with incisors fused, outer group blunt with "shearing" surface, inner incisors toothed; prostheca of right mandible bifid, margin between incisors and molars smooth with tuft of short bristles near molars; left mandible with margin between incisors and molars serrated.

The adult imago is described above, but it is consistent with most adults in the Baetidae and differs from the adult of *Offadens frater* by the fusion of the T1 and T2 with the tibiae of the mid and hind legs. It is unknown if this is consistently expressed by adults of *Edmundsiops*, and whether or not this character is a generic characteristic. As a consequence, adults collected at various sites cannot confidently be placed in a genus, whereas the nymphs clearly can be determined.

This species is widespread throughout eastern Australia in Tasmania, Victoria and New South Wales, being common in fast-flowing riffles in mountain and foothill streams that have a cobble substratum. It is one of the most commonly recorded species and is recorded as *Baetis* MVsp 3 by Metzeling *et al.* (1984), Marchant *et al.* (1985), Doeg (1984), Suter (1997) and Pardo *et al.* (1998). Details of the life cycle of *Edmundsiops hickmani* were given by Pardo *et al.* (1998).

Cloeon tasmaniae Tillyard

Cloeon tasmaniae Tillyard, 1936: 53 [Type species]
Cloeon tasmaniae Scholes 1961(Scholes, 1961): 38

Type material

Holotype male imago: Macquarie River, "Stewarton", 8th February, 1933, E. Scott, British Museum of Natural History.

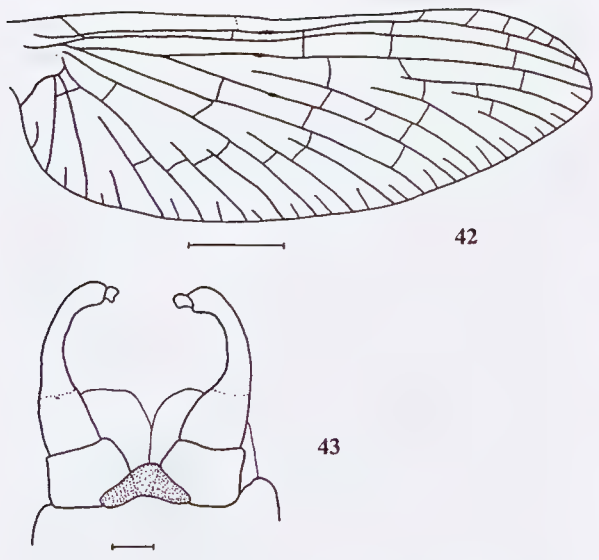
Additional material examined

Tasmania: 5 nymphs and 1 associated adult all on slides, Elizabeth River at Campbell Town, 9.iii.1994, 41°57'S 147°29'E, PJS; 2 nymphs on slides, Macquarie River at "Stewarton", 3.vi.1990,41°49'S 147°15'E, SC; 2 nymphs on slides, Macquarie River at "Stewarton", 1.vii.1992, 41°49'S 147°15'E, SC; 4 nymphs, Basin Ck at Dianas Basin, 10.ii.1995, 41°22'E 148°16'E, PJS and PG; 4 nymphs, Dark Hollow Ck near Beaumaris, 10.ii.1995, 41°25'S 148°18'E, PJS and PG.

Description

Imago

The imago was fully described by Tillyard (1936) and the wing, body and genitalia were all illustrated. However, for completeness the forewing (fig. 42) and genitalia (fig. 43) of the reared adult male are presented. The generic characteristics of this genus are: male compound eye turbinate, separate; hindwing absent, forewings with single intercalaries



FIGS 42–43. Cloeon tasmaniae *male imago. (42) Forewing; (43) Genitalia, ventral. Scales: fig. 42 – bar = 1 mm; fig. 43 – bar = 0.1 mm.*

extending from the radial to the cubital sectors; forceps 3-segmented; cerci present, appendix dorsalis absent.

Mature nymph

Body length 3.1–6.5 mm, cerci 3.5 mm, terminal filament 2.8–3.0 mm.

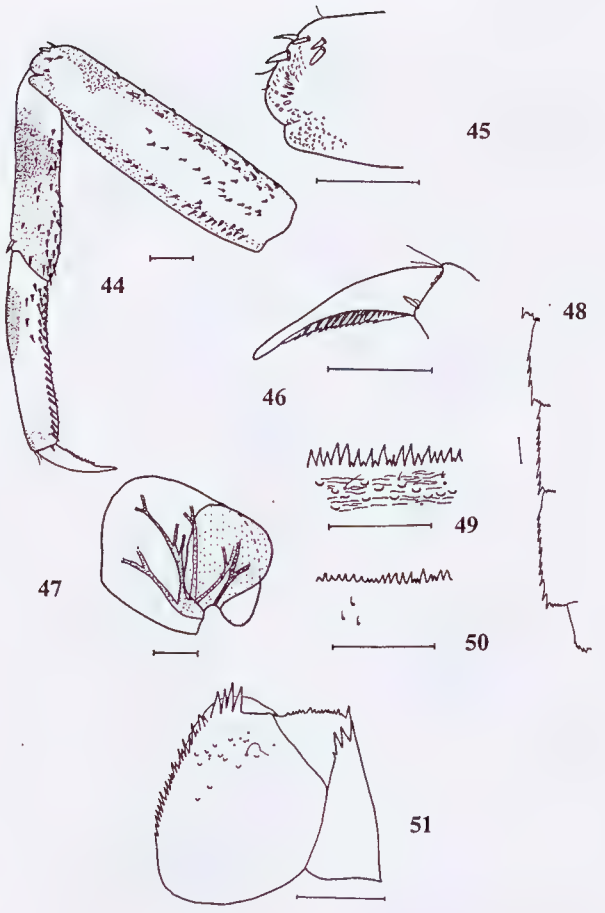
Pronotum narrower than head, light brown. Mesothorax light brown; metathorax light brown with black wing pads present in mature nymphs. Legs banded with one band per segment; fore legs with margins of femora with 9–16 short spine setae (fig. 44), mesial margin with numerous fringed spine setae, apex of femur rugose with two spines (fig. 45); fore tibiae with outer margin with few fine hairs, inner margin with 9–12 short spine setae; outer margin of tarsi without setae except 1 fringed setule at apex, occasional short hairs present; inner margin with 20–25 short fringed setae, tarsal claws long, 0.42x tarsal length, with two proximal rows of fine denticles extending over half claw length (fig. 46). Middle legs with margins of femora with 9–14 short setae and few hairs; mid tibiae with outer margins with 0–3 short spine setae and occasional hairs, inner margins with 11–17 spine setae; outer margins of tarsi without setae, few hairs present, inner with 17–20 short fringed setae; tarsal claws long, 0.46x tarsal length, with two proximal rows of fine denticles extending over half claw length. Hind legs with margins of femora with 16–28 short spine setae; hind tibiae with outer margin lined with 8–13 short spine setae, inner margin with 18–20 spine setae; outer margin of tarsi without setae, but occasional short hairs present, inner margin with 16–20 short fringed setae; tarsal claws with two proximal rows of fine denticles extending over half claw length.

Ratios of leg segments:

fore leg	1.00:0.61:0.69 (0.71 mm);
middle leg	1.00:0.66:0.60 (0.80 mm);
hind leg	1.00:0.62:0.59 (0.91 mm).

Femur length to width ratios: fore leg 4.22 (3.74–5.00), middle leg 4.45 (4.11–5.08), hind leg 5.51 (4.42–7.25).

Abdominal segments 1–7 with gills, segments 1–6 with double, round-ovate, plate-like gills and segment 7 with a



FIGS 44–51. Cloeon tasmaniae *nymph: (44) Fore leg; (45) Apex of fore femur; (46) Fore tarsal claw; (47) 4th gill; (48) Spines on lateral margins of abdominal segments 7-10. (49) Spines on posterior margin of 5th abdominal tergite; (50) Spines on posterior margin of 8th abdominal sternite; (51) Left paraproct, ventral. Scale: bars = 0.1 mm.*

single plate-like gill, all strongly tracheated (fig. 47). Dorsal colour pattern with distinct brown spots on segments 2 and 5, segments 4 and 10 light brown without markings, all other segments with dark brown patterns (fig. 63). Lateral margins of segments 5–9 with spines, postero-lateral margins with short spines (fig. 48). Posterior margins of tergites with distinct sharp teeth and slightly rugose surface with scale scars present (fig. 49). Posterior margins of sternites with short regular teeth, scale scars rare (fig. 50). Paraprocts with 15–32 well-developed spines on inner and apical margins, scales rare (fig. 51).

Labrum (fig. 52) rectangular (length 0.71x width), with a deep concavity in centre of the anterior margin, which is lined with fine fringed setae, numerous spine setae posterior to margin. Mandibles lack marginal setae, incisors separate and toothed. Right mandible (fig. 53) with outer incisors with 4 teeth, inner incisors with 3–4 teeth, inner margins rugose, prostheca robust with 5 apical teeth (fig. 54), tuft of setae between incisors and molars well developed. Left mandible (fig. 55) with 4 teeth on the outer incisors, inner incisors with 3–4 teeth, prostheca robust with 3-4 tubercles and a basal spine (fig. 56), tuft of setae between incisors and molars well developed. Maxilla (fig. 57) with a 3-segmented palp, inner margin of galeo-lacinia with 4–5

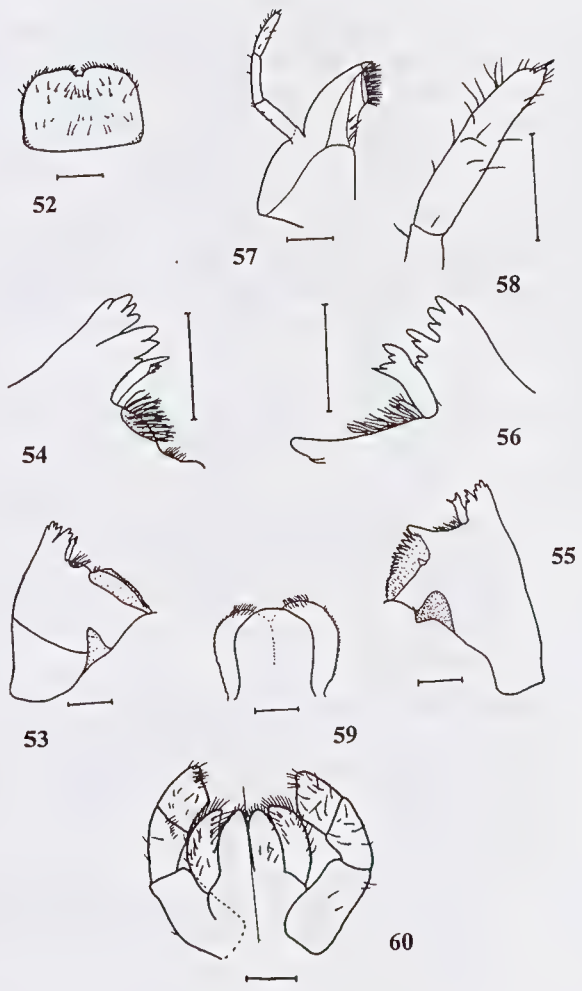
medial setae and a single inner setule, palpi longer than galeo-lacinia, apical segment with a single spine at apex (fig. 58), segment ratios 1.00:0.85:0.90 (0.20 mm). Hypopharynx (fig. 59) with rounded lingua. Labium (fig. 60) with glossae and paraglossae curved and pointed, labial palpi with 3 segments, apical segment almost square with slight apical concavity, proximal segment of labial palp 1.82x longer than broad, segment ratio 1.00:0.92:0.59 (0.20 mm).

Notes on *Cloeon*

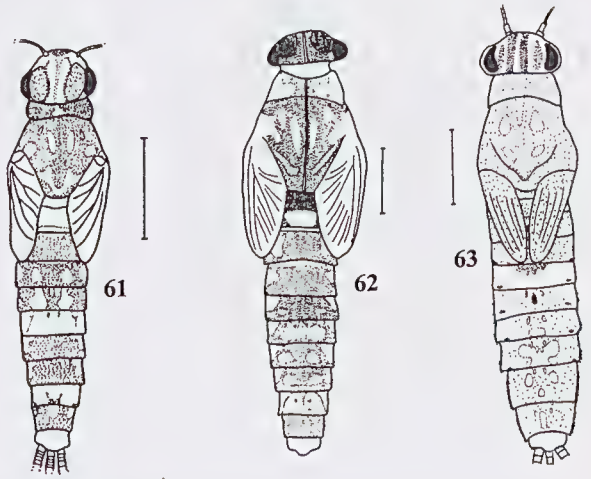
Cloeon tasmaniae was first described as an adult by Tillyard in 1936 from the Macquarie River at "Stewarton". Tillyard (1936) did not record the nymph and it has never been described. After successfully rearing a nymph from the Elizabeth River at Campbell Town, which was conspecific with nymphs from the type locality, and the adult of which was consistent with the adult description given by Tillyard (1936), it is now possible to provide a description of the nymph of *Cloeon tasmaniae*.

Cloeon tasmaniae can be distinguished from the other two fully described species of *Cloeon* from Australia (*C. fluviatile* Ulmer and *C. paradieniense* Suter) and the two other described adult species (*C. nandirum* Harker and *C. virens* Klapálek) by the following combination of characters: Adults: males with buff/pink turbinate eyes, third segment of forceps globular, femora and tibiae of fore legs long with tibia 1.8x longer than femur; females with milky opaque pterostigma. Nymphs: with banded legs, outer margin of tibiae lacking setae, inner margins of fore tibiae with <15 setae, inner margin of mid and hind tarsi with <20 setae, fore tarsus with 20–25 setae, tarsal claws all with denticles extending over half claw length, prostheca of right mandible robust with 5 apical teeth, maxillary palpi 3-segmented, apical segment of palp with spine apically, inner margin of galeo-lacinia with 4–5 medial setae and a single inner setule, hypopharynx with rounded lingua, basal segment of labium broad (length/width = 1.82), abdomen with spines on lateral margins of segments 5–9.

Tables 1 and 2 (pp. 73, 74) are an updated compilation of characters previously provided by Suter (1986) comparing the known Australian species of *Cloeon*. Characteristics for *C. virens* have been sourced from the descriptions given by Klapálek (1905) and Ulmer (1919), and for *C. nandirum* Harker's (1957) description has been used. A key is not provided at this stage, as it is likely that other undescribed species exist in Australia and it is, therefore, premature to do so. The table does provide a list of characters of the described species from which verification of identification can be made. *C. fluviatile* possesses a 2-segmented maxillary palp and not a 3-segmented palp as incorrectly recorded by Suter (1986). *Cloeon tasmaniae*, *C. paradieniense* and *C. nandirum* all possess 3-segmented maxillary palpi but *C. tasmaniae* is the only one of these three species with clearly banded legs. In addition, *C. tasmaniae* has been recorded in northern Tasmania, but it is likely to be widespread in still waters throughout the State. *C. tasmaniae* has not been recorded on the Australian mainland, while all the other species have only been recorded from the Australian mainland.



FIGS 52–60. Cloeon tasmaniae, *nymph. (52) Labrum; (53) Right mandible; (54) Enlarged incisors and prostheca of right mandible; (55) Left mandible; (56) Enlarged incisors and prostheca of left mandible; (57) Maxilla; (58) Enlarged terminal segment of maxillary palp; (59) Hypopharynx; (60) Labium, dorsal (left of midline) and ventral (right of midline). Scale: bars = 0.1 mm.*



FIGS 61–63. Dorsal colour patterns on nymphs of (61) Offadens frater*; (62)* Edmundsiops hickmani*; (63)* Cloeon tasmaniae. *Scale: bars = 1 mm.*

ACKNOWLEDGEMENTS

I would like to thank Australian Biological Resources Study and the Land and Water Resources Research and Development Corporation for financial support during this study. Without this assistance the amount of material examined would be significantly less. I wish to thank Jenny Beer for her painstaking dissections and measurements of much of the material and Peter Goonan, my wife Anne and children Stephanie and Matthew all of whom gave valuable assistance in the field while collecting in Tasmania. Thanks also to all who have provided material from ecological surveys in Tasmania.

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(accepted 29 August 2000)

TABLE 1
Tabulated comparisons of male imagos for all described species of *Cloeon* in Australia

Character	*Cloeon fluviatile* Ulmer	*C. paradieniense* Suter	*C. tasmaniae* Tillyard	*C. nandirum* Harker*	*C. virens* Klapálek†
Body length	4.1 mm	7.8 mm	7 mm	7 mm	6 mm
Forewing length	4.3 mm	7.1 mm	6 mm	4 mm	6 mm
Forewing width	1.6 mm	2.4 mm	2.4 mm	1.6 mm	2.3 mm
Cerci length	8.5 mm	15.7 mm	12 mm	?	11-12 mm
Eye colour	Sepia	Yellow	Buff-Pink	Orange	?
Pterostigma crossveins	2–4	3–4	5	4–5	5
C/Sc proximal crossveins	0	2–5	0–3	0	6
Sc/R crossveins	0	2–6	0–5	0	7
Costal colour	Milky in males and females	Milky in males, red-brown in females	Milky in males and females	Milky	Emerald green in females
Fore leg: Femur length	0.8 mm	1.48 mm	1.8 mm		
Tibia: Femur length	1.76	1.68	1.82		
Tarsus 1:Femur l	0.07	0.05	0.07		
Tarsus 2:Femur l	0.68	0.70	0.77		
Tarsus 3:Femur l	0.49	0.50	0.56		
Tarsus 4:Femur l	0.27	0.28	0.29		
Tarsus 5:Femur l	0.20	0.18	0.17		
Forceps: terminal segment	Short and narrow	Triangular	Globular	Long and narrow	Short and narrow
Penes covers	Rectangular, flat apically	Rectangular, pointed apically	Rectagular, flat apically	?	?
Dorsal body pattern	Red-brown with distinct marking on 1–7	Red-brown with light dorsal stripe on 1–7	Brown, darker from 7–10		
10th abdominal segment	Uniform red-brown	Light	Brown		

* Characteristics for *C. nandirum* after Harker (1957).
† Characteristics for *C. virens* after Klapálek (1905) and Ulmer (1916).

TABLE 2
Tabulated comparisons of mature nymphs for all described species of *Cloeon* in Australia

Character	*Cloeon fluviatile* Ulmer	*C. paradieniense* Suter	*C. tasmaniae* Tillyard	*C. nandirum* Harker*	*C. virens* Ulmer
Nymph					Unknown
Body length	5.1–6.7 mm	8 mm	3.1–6.5 mm	6.0 mm	
Cerci length	3.5–6.2 mm	6.2 mm	3.5 mm		
Terminal filament length	3.3–5.0 mm	4.6 mm	2.8–3.0 mm		
Legs	Banded	Not banded	Banded	Not banded	
Fore leg: femur length	1.01mm	1.44 mm	0.71 mm		
Tibia/femur	0.63	0.67	0.61		
Tarsus/femur	0.63	0.58	0.69		
Femur length/width	4.92	5.18	4.24		
Tibia with apical setule	P/A	P/A	Present		
Tibial setae: outer	0–2	0–2	0		
Tibial setae: inner	15–27	25	9–12		
Tarsal setae: outer	0	0	0		
Tarsal setae: inner	19–32 on full length	44 on full length	20–25 on full length		
Tarsal claw teeth	Fine < 1/2 length	Large > 1/2 length	Large > 1/2 length		
Middle leg: femur length	1.04 mm	1.56 mm	0.80 mm		
Tibia/femur	0.64	0.67	0.66		
Tarsus/femur	0.58	0.51	0.60		
Femur length/width	4.81	6.05	4.45		
Tibia with apical setule	P/A	Absent	Present		
Tibial setae: outer	0–1	10	0		
Tibial setae: inner	12–23	32	11–17		
Tarsal setae: outer	0	0	0		
Tarsal setae: inner	16–25 on full length	27 on full length	17–20 on full length		
Tarsal claw teeth	Fine < 1/2 length	Large > 1/2 length	Large > 1/2 length		
Hind leg : femur length	1.10 mm	1.68 mm	0.91 mm		
Tibia/femur	0.62	0.79	0.62		
Tarsus/femur	0.56	0.60	0.59		
Femur length/width	4.95	6.51	5.51		
Tibia with apical setule	P/A	Present	Present		
Tibial setae: outer	0–5	19	0–1		
Tibial setae: inner	18–27	45	18–20		
Tarsal setae: outer	0	0	0		
Tarsal setae: inner	19–28 on full length	17 on apical 1/2 only	16–21 on full length		
Tarsal claw teeth	Fine < 1/2 length	Large > 1/2 length	Large > 1/2 length		
Paraproct spines	14–28	27–30	15–32		
Abdominal segments lateral margins spines	6–9	7–9	5–9		
Mouth parts					
Labrum: length/width	0.66	0.66	0.71		
Maxillary palpi	2 segments	3 segments	3 segments	3 segments	
Basal segment length	0.17 mm		0.12 mm		
Mid/basal segment	–	0.69	0.85		
Apical/basal segment	1.49	0.88	0.90		
Galeolacinia setae	4+1	5+1	5+1		
Hypopharynx	Convex	Convex with medial nipple	Convex		
Labial palpi: basal length	0.23 mm	0.33 mm	0.20 mm		
Mid/basal	0.76	0.56	0.92		
Apical/basal	0.65	0.48	0.59		
Basal length/width	1.96	2.74	1.82		

* Characteristics for *C. nandirum* are after Harker (1957).

GENETIC VARIATION IN THE *EPACRIS TASMANICA* COMPLEX (EPACRIDACEAE)

by C. A. Gilmour, R. K. Crowden, R. E. Vaillancourt and A. Koutoulis

(with two text-figures)

Gilmour, C.A., Crowden, R.K., Vaillancourt, R.E., & Koutoulis, A., 2000 (31:xii): Genetic variation in the *Epacris tasmanica* complex (Epacridaceae). *Pap. Proc. R. Soc. Tasm.* 134: 75–78. School of Plant Science, University of Tasmania, GPO Box 252-55, Hobart, Tasmania, Australia 7001.

Random amplified polymorphic DNA markers (RAPD) were used to delimit species in the *Epacris tasmanica* complex (Epacridaceae) collected from various locations in Tasmania, Australia. The RAPD analysis placed morphologically similar taxa located closely geographically into discrete clusters. However, geographically distant populations of morphometrically similar taxa, such as the southern and northern Tasmanian populations of *E. virgata* and *E. tasmanica,* were less closely related to each other than those taxa classified as different species. The most geographically remote population (*E. glabella* [Serpentine Hill]) shared the least genetic similarities with the other taxa. The genetic information obtained from this study reinforces some previous morphometric data used to delimit species in the *E. tasmanica* complex. Furthermore, the strong geographical structure of the genetic variation is consistent with a model in which gene flow between populations is limited.

Key Words: ***Epacris tasmanica*** **complex, genetic variation, RAPD analysis, endangered species.**

INTRODUCTION

The Epacridaceae is one of the five main families that dominate Australian heathlands. The high level of endemism and localised distributions of the Epacridaceae leave many taxa susceptible to extinction. The *Epacris tasmanica* complex comprises seven closely related taxa, all of which are Tasmanian endemics (Crowden & Menadue 1990). Historically, interest has been shown in the delimitation of species of this complex, primarily to clarify the taxonomic relationships between taxa. However, with the listing of six of the seven species of the complex as endangered or vulnerable (Flora Advisory Committee 1994), it is of interest to clearly identify discrete genetic entities to aid in their conservation.

The overlap of vegetative and floral characteristics between taxa in the *E. tasmanica* complex has made separation of distinct species difficult when using identification keys based on plant habit as well as leaf and sepal characteristics (Curtis 1963, Jarman & Crowden 1977), which can be extremely plastic. Other attempts to delimit taxa in the *E. tasmanica* complex have used characters such as pollen surface patterns (Matthews 1965, 1966, Menadue & Crowden 1991) and flavonoid chemistry (Jarman 1975). Crowden & Menadue (1990) used numerical taxonomical methods to revise a key for the *E. tasmanica* complex and suggested there are seven taxa in the complex: *E. tasmanica, E. virgata, E. apsleyensis, E. barbata, E. exserta, E. stuartii,* and *E. glabella* (described by Jarman & Mihaich 1991 as *E.* aff. *exserta* [Tunnel Hill]).

Molecular markers are simply inherited characters that distinguish or mark underlying genetic differences between individuals. It is believed that DNA markers are not severely influenced by selection (Avise 1994) and they have been increasingly used to study patterns of relatedness in natural populations (Ritland & Ritland 1996). Randomly amplified polymorphic DNA (RAPD) markers have proved to be very effective in differentiating various degrees of relatedness (Williams *et al.* 1990, Cambecedes *et al.* 1999). They generally have been used within species but are also useful in population studies, when investigating complexes of closely related species; the *E. tasmanica* complex is such a complex. In fact, systematists are increasingly using RAPD markers and Harris (1995) demonstrated that groupings based on RAPD and restriction fragment length polymorphism (RFLP) analysis were essentially the same in species of *Leucaena* (Leguminosae). In the present study, RAPD markers were used to analyse genetic variation between members of the *E. tasmanica* complex collected from several locations in Tasmania, with a view to clarify the taxonomic relationships between members of this complex.

METHODS

Tissue Collection and DNA Isolation

Tissue samples were collected from 19 Tasmanian populations (fig. 1). New shoots and floral buds were collected from ten representative individuals in each population and individually stored at 4°C in airtight plastic bags, until processed (tissues were stored for a maximum of one week). Young tips were used, as it was expected that this tissue would contain less polysaccharide storage materials and, therefore, provide cleaner DNA compared to mature tissues. In the initial collection (June–July 1996) insufficient new growth was observed on the majority of plants to obtain enough tissue for individual DNA extraction. In some exposed populations, where growth was restricted by local severe environmental conditions (Southport Bluff [*E. stuartii*] and Cape Tourville [*E. barbata*]), it was difficult to obtain fresh plant tissues. In the *E. stuartii* and *E. barbata* populations, tissue was collected from only eight individuals per population. At sites visited later (August–September 1996), when many of the *Epacris* species were beginning to flower, floral buds were also collected to determine their value as a DNA source. Where possible, paler coloured buds were preferentially selected to minimise anthocyanin levels, which might have hindered DNA extraction and analysis.

Preliminary DNA extraction trials showed that 2–5 g of tissue were required to obtain DNA. Due to the lack of available tissue for DNA extraction, tissues from individual plants were pooled in equal proportions to produce a mixture for each population (as discussed in Cambecedes *et al.* 1999). This procedure made it impossible to investigate

FIG. 1 — Collection sites (numbers) and RAPD groups (letters) for E. tasmanica *complex populations.* E. virgata *(School Hill [1], Snug "High" [2], Van Morey Rd [3], Southern Outlet [4]);* E. tasmanica *(Hospital Creek [5], Buckland [6], Paradise Gorge [7], Lake Leake Rd [8], "0" Rd [9], Barbers Creek [10], Reynolds Hill [11], Hardings Falls [12]);* E. virgata *(Old Railway [13], Scots Hill [14]);* E. stuartii *(Southport Bluff [15]);* E. glabella *(Serpentine Hill [16]);* E. virgata *(Mt Cameron [17]);* E. barbata *(Cape Tourville [18]);* E. exserta *(Trevallyn Dam [19]). Letters delineate RAPD groups defined in figure 2.*

differences within populations; however, it enabled the efficient detection of differences among populations. Tissues were dried in McCartney bottles containing desiccator crystals, or frozen in liquid nitrogen and stored below –60°C until DNA extraction. Preliminary extractions using floral buds produced high yields of DNA that possessed a similar amount of polysaccharide contamination to that observed in leaves. Consequently, where floral buds were collected, they were used in conjunction with leaf material. DNA was extracted by the CTAB (cetyltrimethyl ammonium bromide) method of Doyle & Doyle (1990), using 5 g of tissue from each population (0.5 g or 0.625 g from each plant when ten or eight samples were collected per population, respectively). For several samples, particularly where leaf material was the only source of DNA, an additional chloroform-isoamyl alcohol extraction was performed prior to DNA precipitation to remove contaminants. To remove further contaminants, the salt concentration of the solubilised DNA was adjusted to 2.5 M with ammonium acetate, and the solution was placed at –20°C for 5 min. prior to extraction with phenol: chloroform (1:1). For most samples, the ammonium acetate and phenol:chloroform extractions were repeated at least twice. Following the cleaning up procedures, DNA was precipitated in cold ethanol, washed with ethanol, and re-suspended in 500 µL of TE buffer to ensure that the different extraction methods did not effect amplification. DNA was quantified using a Hoefer TKO-100 Mini-fluorometer (Hoefer Scientific Instruments, USA) and diluted in sterile water to 3 ng.µL^{-1}.

RAPD Analysis

Various primer and magnesium ion concentrations for DNA amplification of *Epacris* species were tested. The best DNA amplification was obtained in polymerase chain reaction (PCR) mixtures (15 µL final volume) containing 1.5 µL Taq polymerase buffer (x10), one unit Taq polymerase (Boehringer, Germany), 100 µM of each dNTP, 1.6 mM $MgCl_2$, 150 µg.mL^{-1} BSA, 0.25 µM primer and 12 ng genomic DNA (modified from Williams *et al.* 1990). DNA amplification was performed in a Corbett Research Fast Thermal Sequencer (FTS-960) (Corbett Research, Australia) programmed as follows: initial denaturation of 2 min. at 94°C; 35 cycles of 1 min. at 92°C denaturation, 1 min. at 35°C annealing, 2 min. at 72°C extension; and a final extension of 5 min. at 72°C. A total of 233 10-base primers from UBC (University of British Columbia, Canada) and Operon (Operon Technologies, USA) were screened on the Lake Leake DNA samples (the most abundant sample of DNA). Only 18 of these primers were used in the final analysis, as they produced reproducible products (see Results).

Amplified PCR products were separated using a 1.4% (w/v) agarose gel in TBE buffer containing 0.5 µg.mL^{-1} ethidium bromide. RAPD bands were visualised on an UV transilluminator and photographed using positive/negative polaroid film (Polaroid 665, USA). All polymorphic bands between 517 and 2645 base pairs were scored, while monomorphic bands were not scored. Each sample was scored manually for band presence (1) or absence (0) and data were recorded in the form of a binary matrix. A similarity matrix was generated using the Simple Matching Coefficient Function of NTSYS-pc (numerical taxonomy system of multivariate statistical programs for PC) (Rohlf 1993). The similarity matrix was used to generate an UPGMA (unweighted pair-group method with arithmetic mean) dendrogram using the SAHN (sequential agglomerative hierarchical non-overlapping) cluster analysis and UPGMA programs in NTSYS-pc (Rohlf 1993).

RESULTS

Of the 233 arbitrary primers screened, 175 produced amplification of the *Epacris* DNA fragments to varying degrees. However, only 54 of these 175 primers produced RAPD amplification products which were clearly defined and had minimal background smearing. Due to reproducibility problems encountered with some primers, only 18 of the 54 primers were used in the final analysis (UBC 4, 11, 25, 31, 60, 64, 76, 83, 93, 249 and Operon D10, D13, F06, F07, F14, F20, M05, M18). These 18 primers produced 57 scorable polymorphic bands that were used to generate the similarity matrix and UPGMA dendrogram (fig. 2).

The UPGMA dendrogram demonstrates that populations in close geographic proximity formed tight clusters. The groupings do not correspond well to the previous described species, with the two more widespread species split geographically, with all the southeastern Tasmanian populations being grouped together, regardless of species, and geographically distinct populations of the same species from this region becoming more and more distinct. The *E. virgata* populations were divided into three groups, broadly corresponding to geography (figs 1, 2). All populations that were sampled and described by Crowden & Menadue

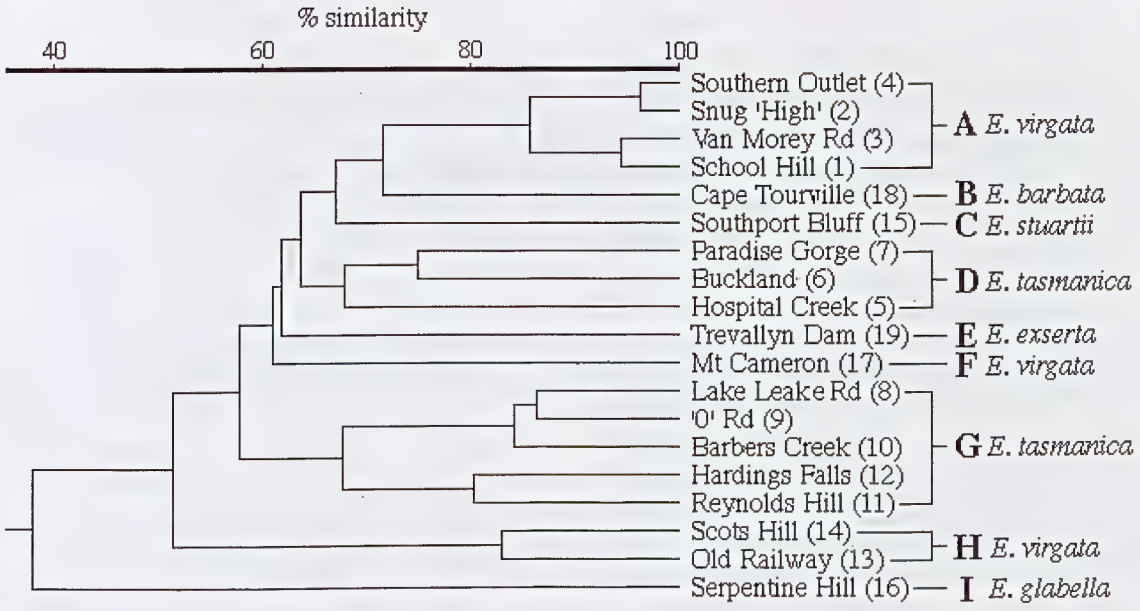

FIG. 2 — UPMGA dendrogram based on RAPD data obtained from populations of the E. tasmanica *complex. Numbers in parentheses refer to the collection sites (fig. 1), while letters in bold refer to RAPD groups.*

(1990) as southern *E. virgata* were tightly clustered, suggesting a close genetic relationship between these populations (Group A). The two northern *E. virgata* populations (Scots Hill and Old Railway) also clustered together (Group H). Populations described as *E. tasmanica* formed two discrete clusters (Groups D and G) separated by *E. exserta* (Trevallyn Dam) (Group E) and a putative disjunct population of *E. virgata* (Mt Cameron) (Group F) (see Discussion). The two *E. tasmanica* clusters do correspond broadly to geography, with populations within each group encompassing approximately 30 km, while approximately 100 km separated the groups.

The dendrogram suggests that the *E. glabella* population (Group I) is an outgroup to the entire *E. tasmanica* complex. However, several primers gave no amplification in the *E. glabella* DNA. Consequently, data were lacking for several reactions, which may have biased the analysis. Interestingly, the positioning of *E. glabella* on the dendrogram does correspond to geography. *E. glabella* occurs in the far northwest of Tasmania, with its closest geographic neighbours being the northern *E. virgata* populations at Scots Hill and Old Railway (Group H).

DISCUSSION

The genetic data generated by RAPD markers have reinforced some of the taxonomic conclusions generated through the morphometric analyses of the *Epacris tasmanica* complex by Crowden & Menadue (1990). The formation of distinct clusters, representing both the same species and similar geographic locations of the populations, suggests a relationship between the geographical location of the population and genetic distances between populations. The overall small differences in genetic similarities between clusters, suggests a close relationship between all members of the *E. tasmanica* complex.

Interestingly, not all RAPD results correspond to the morphometric data of Crowden & Menadue (1990). Although morphometrically similar, there is substantial genetic differentiation between the southern (Group A) and northern (Group H) *E. virgata* populations. According to Crowden & Menadue (1990), the northern *E. virgata* population flower measurements are at the smaller end of the *E. virgata* range but are otherwise indistinguishable from the southern *E. virgata* population. The data, therefore, support a model in which gene flow between populations is limited and local differentiation has occurred. Interestingly, the *E. virgata* population at Mt Cameron shows considerable genetic differentiation from both the southern and northern *E. virgata* populations. Crowden & Menadue (1990) tentatively regarded this taxon (originally lodged in the Tasmanian herbarium as *E.* aff. *exserta* [Mt Cameron]) as an outrider population of *E. virgata,* based on overall habit and appearance. The data in this study add credence to the argument that the *E. virgata* population at Mt Cameron is a well-differentiated population (Crowden & Menadue 1990). Clearly, the *E. virgata* populations at Mt Cameron and at other Tasmanian sites not sampled in this study (e.g. Murdunna and Hospital Creek) require further investigation to determine their genetic relationship within the complex.

Crowden & Menadue (1990) suggested that, due to flower type and other shared morphological characteristics, *E. stuartii* and *E. glabella* are more closely related to *E. virgata* (both southern and northern populations) than *E. tasmanica*. However, the RAPD data suggest that *E. glabella* (Group I) and the northern *E. virgata* populations (Group H) are not closely related to the southern *E. virgata* (Group A) and *E. stuartii* (Group C) populations. Furthermore, researchers have suggested that *E. barbata* is more closely related to *E. tasmanica* than *E. virgata* (Menadue & Crowden 1991); however, the RAPD data presented in the present study cannot address this issue. Unfortunately, RAPD data are lacking for the newly described *E. aspleyensis*, so it is not possible to determine its genetic relationship to the other members of the *E. tasmanica* complex.

The association of geographic separation and genetic similarity observed in the dendrogram may, in part, explain these discrepancies. The geographical distance between the southern and northern *E. virgata* and *E. tasmanica* populations would appear to effectively prevent an exchange of genetic material between populations. Over time, drift and different environmental selective pressures at each site would gradually alter the genetic composition of the taxa. Such a scenario would explain the genetic dissimilarity observed between southern and northern *E. virgata* and *E. tasmanica* populations; however, the question of the maintenance of morphological similarities remains unanswered. Additionally, the close proximity of the southern *E. virgata* and southern *E. tasmanica* populations and their genetic similarity could indicate the mixing of genetic material without a noticeable effect on morphology. The premise that geographical isolation is correlated with genetic variation between related taxa is further illustrated by the positioning of other isolated populations (i.e. *E. stuartii* [Southport Bluff], *E. barbata* [Cape Tourville], *E. virgata* [Mt Cameron], *E. virgata* [Scots Hill and Old Railway Line] and *E. glabella* [Serpentine Hill]). Potts & Jordan (1994) reported that populations of *Eucalyptus globulus* from relatively isolated localities often showed larger genetic variation when compared to less isolated populations, due to inbreeding and localised selective pressures. A study of the genetic variances within the populations could clarify whether there is a high degree of inbreeding in these populations.

Subtle differences in leaf morphology, corolla tube length and geographic isolation of members of the *E. tasmanica* complex, are considered sufficient reasons to maintain *E. stuartii* and *E. glabella* as distinct species (Crowden & Menadue 1990). The RAPD data generated in this study supports the maintenance of *E. glabella* as a distinct species; however, this is less clear for *E. stuartii*. Interestingly, Keith (1996) suggested that the distinctiveness of *E. stuartii* from other taxa in the *E. tasmanica* complex could be strengthened by including several other characters, such as leaf thickness and lustre, inflorescence length, width of basal and ultimate branches, and habit.

In conclusion, this RAPD analysis of the *E. tasmanica* complex placed populations of morphologically similar taxa into discrete clusters, which corresponded (in varying degrees) with the geographical location of the populations within the *E. tasmanica* complex. The division of *E. virgata* and *E. tasmanica* into southern and northern groups is consistent with a model in which gene flow between populations is limited and should be investigated further. The fact that not all RAPD results corresponded to the morphometric data of Crowden & Menadue (1990), suggests that it may be simplistic to assume that one methodology is sufficient to address the taxonomic issues in the *E. tasmanica* complex. Further research, therefore, should have a combinatorial approach and include morphological, genetic and breeding systems.

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THE EARLIEST TAXONOMIC DESCRIPTION AND ILLUSTRATION OF AN AUSTRALIAN REPTILE: ANOTHER HISTORICAL FIRST FOR BLUETONGUE LIZARDS (SQUAMATA: SCINCIDAE: *TILIQUA*)

by Glenn M. Shea

(with one plate)

SHEA, G.M., 2000 (31:xii):The earliest taxonomic description and illustration of an Australian reptile: another historical first for bluetongue lizards (Squamata: Scincidae: *Tiliqua*). *Pap. Proc. R. Soc. Tasm.*, 134: 79–82. ISSN 0080–4703. Department of Veterinary Anatomy and Pathology, University of Sydney, NSW, Australia 2006.

Manuscript descriptions of several species of reptiles prepared in 1777 by William Anderson, naturalist on James Cook's third voyage of discovery, are reported and, where possible, identified. The most thorough description is of the Blotched Bluetongue, *Tiliqua nigrolutea*, based on a specimen collected from Adventure Bay, Bruny Island, and painted by the artist John Webber. This description, though not previously published, is the earliest known formal scientific description of an Australian reptile, and the painting is the earliest scientific illustration of an Australian reptile.

Key Words: history, Tasmania, systematics, Squamata, Scincidae, *Tiliqua*.

While no thorough formal historical study of Australian herpetology has yet been undertaken, Whitley (1970) and Tyler (1976) provide some details of the early history. Although there are a few earlier mentions, either explicit or (by naming of localities) implicit, of the occurrence of sea turtles and crocodiles in Australian waters, Dampier (1729), in an account widely reprinted (Flinders 1814, Alexander 1914, Ride 1962, Serventy 1970, Whitley 1970, Serventy & Raymond 1974, Stanbury 1978, Stanbury & Phipps 1980, Stanbury 1987, Greer 1989), provides the earliest description of an Australian reptile that is identifiable to species. Dampier's account is evidently of a Shingleback (*Tiliqua rugosa*), seen at Shark Bay in 1699. Dampier's description, however, antedates the introduction of formal binomial nomenclature by Linnaeus, and only refers to the lizard as the New Holland Guano (a presumed corruption of iguana, also later corrupted to produce the Australian term goanna).

Just over 60 years after Dampier's account, the earliest published scientific descriptions of Australian reptiles appeared in White's (1790) *Journal of a Voyage to New South Wales*. Although there is some controversy over the authorship of the species names proposed (e.g. Sherborn 1891, Alexander 1924, Tyler & Dobson 1973, Shea 1993), it is generally recognised that most of the descriptions of animals were the work of George Shaw and John Hunter. Five names were applied to Australian lizards, each of which was accompanied by a formal diagnosis and illustration, although an additional six snakes and one lizard were illustrated and briefly described without application of names. The first reptile description to appear (White 1790: 242) is *Lacerta scincoides*, now known as *Tiliqua scincoides*, the Eastern Bluetongue Skink.

Thus, bluetongue lizards were the earliest Australian reptiles described in print and the first Australian reptiles to receive a formal scientific name.

The account in White's *Journal*, however, is not the earliest formal scientific description and illustration of an Australian reptile. During James Cook's third, fatal voyage to the Pacific, between 1776 and 1780 in the ships *Resolution* and *Discovery*, he stopped at Adventure Bay, on Bruny Island off eastern Tasmania, in January 1777. While there, the naturalist on the voyage, the surgeon William Anderson, observed and described a large lizard. Anderson, like Cook, died during the voyage. When James Douglas prepared Cook's account for publication, he included numerous excerpts from Anderson's manuscript journal. Thus, Cook's *Voyage ..., Vol.I* (1784: 110) included Anderson's description of his lizard: "we killed a large, hitherto unknown, lizard, fifteen inches long and six round, elegantly clouded with black and yellow". This account was repeated by Eden (1787). Anderson's manuscript journal was finally published by Beaglehole (1967); here the same passage reads: "a large Lizard above fifteen inches long and six round, elegantly clouded with black and yellow was kill'd", with a footnote indicating the name "*Lacerta tarda*".

Both Beaglehole (1967) and Whitley (1970) identify Anderson's lizard as *Tiliqua nigrolutea*, the largest lizard in Tasmania and the only one to attain the size described. Whitley also noted (1970: 55) that Anderson's manuscript descriptions, in the British Museum (Natural History), now the Natural History Museum, London, contain Latin descriptions of the animals from Tasmania, and that the large lizard was painted by John Webber, one of the artists on the expedition (1970: 60). However, Whitley published neither description nor illustration.

Webber's painting of the lizard, now in the collection of the Department of Prints and Drawings at the British Musuem, is also mentioned by Beaglehole (1967: ccxiv), and again in a catalogue of the artwork of the expedition (Joppien & Smith 1985), but it has only recently been published for the first time (Shea 1998). The illustration (pl. 1) is in pen and black ink with watercolour over graphite (C. Serhan, pers. comm.), and is unequivocally identifiable as *Tiliqua nigrolutea*.

Through the courtesy of Ms Ann Datta, I have been able to obtain a copy of Anderson's full manuscript description of this animal (Anderson 1776–78). The Latin description appears twice, the first time on p.8, the second time on p. 28, where it is accompanied by an English translation. The second Latin description (here published for the first time, with line breaks indicated) reads:

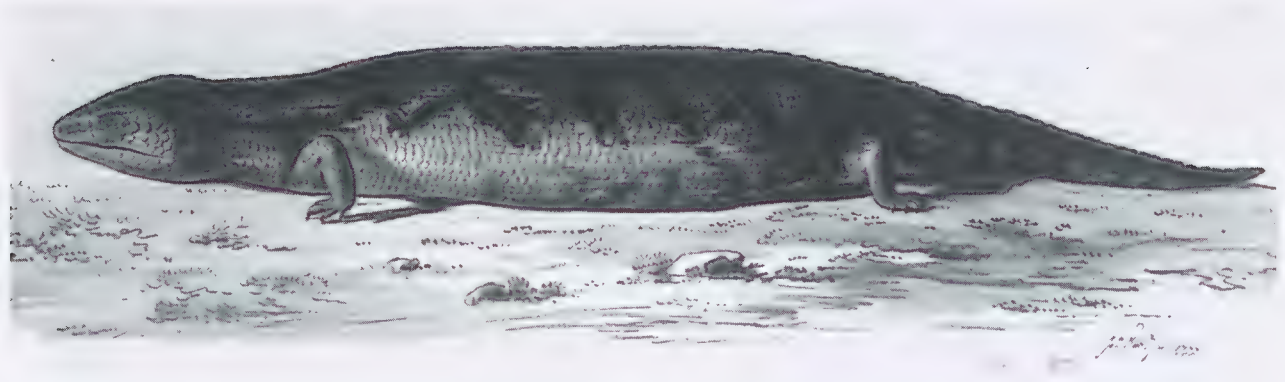

*FIG. 1 — Monochrome reproduction of John Webber's painting of a blotched bluetongue (*Tiliqua nigrolutea*) from Adventure Bay, Bruny Island, Tasmania.*

12. Lacerta tarda

Longitudo unciae quindecem, quorum [sic] Cauda tantum 5 est - /Circumferentia unciae sex.
Corpus depressum, imbricatum, squamis validis subrotundis. /Cauda teres, crassa, sensim versus apicem decrescens./Buccae subgibbosae, subflavae, auribus perspicuis. Pedes /pentadactyli, unguiculati. Vertex fuscus - Corpus supra /ex luteo nigroque oblique undulatum, s[eu] obscure decussat/um - Corpus subtus cinereus, sed cauda nigro variega/ta - Lingua lata, obtusa, livida, carnosa. /Habitat in terra Diemeni - Ambulat tarde.

The English description, which mostly corresponds to the Latin version, reads:

12. Drawing Lacerta tarda: or slow Lizard.
The Length fifteen inches, of which the tail is only five. - /The Circumference - six inches./
The body flatted & coverd with large roundish scales. /The tail round, thick & gradually decreasing towards the point. /The cheeks somewhat gibbous & yellowish, with very conspicu/ous Ears behind. - The feet have five toes furnish'd with claws. /The top of the head brown - The upper part of the body wav'd, /or rather obscurely cross'd obliquely, with black and yellow. / Underneath it is of an ash colour, but varied with black on /the tail - The tongue broad, blunt, thick or fleshy, & livid - /It inhabits Van Diemens Land. /Fig. pict. Webber.

The first Latin description differs from the later version only in minor points. Apart from punctuation, the only differences are "quinque" for "5 est", "subconcavis" for "perspicuis", the omission of "Corpus" before "subtus cinereum", the change in order of "obtusa, livida, carnosa" to "carnosa, obtusa, livida", and the omission of reference to the illustration.

This description and illustration, although unpublished until recently, appear to be the first formal description and European illustration of an Australian reptile. This is also among the earliest post-Linnaean names applied to any reptile species. Further, Anderson was the first to report the blue tongue which now gives the genus its common name, bluetongue lizard, a name which first appeared in the published literature over a century later (Anon 1885).

The description of *Lacerta tarda*, though brief by modern standards, is not only quite acceptable by the standards of the day but positively loquacious. Anderson used as his herpetological reference Linnaeus' *Systema Naturae* (Keevil 1933), in which most lizards were placed in a single genus, *Lacerta*, accompanied by brief diagnoses of a few lines. Although Laurent (1768) had initiated the dismemberment of this genus, his changes were not adopted by English scientists for many years. The later lizard descriptions in White's (1790) *Journal* are likewise all referred to *Lacerta*.

Anderson's description refers to colouration, body size and shape, number of digits and claws, all treated as major diagnostic features in contemporary lizard descriptions and sufficient to differentiate the species from the 48 *Lacerta* species listed by Linnaeus (Linné 1766).

Webber's illustration, likewise, concentrates on body proportions and, to a lesser extent, colour pattern. The lack of attention to the configuration of head scales is typical of other illustrations of the period. The importance of scale configuration, size and number in differentiating lizard species was not appreciated until the following century.

The fate of Anderson's specimen remains unknown, if, indeed, it was retained by him to send home. Keevil (1933) suggested that some of the collections remained in Russia, as security for supplies received, while Whitehead (1969) and Medway (1979) document the tortuous routes followed by the material that returned to Sir Joseph Banks in London. Of the extant museums thought to have received material from Cook's voyages, there are no identifiable Anderson or Banks specimens of *Tiliqua nigrolutea* in Leningrad (Strauch 1866), Vienna (Fitzinger 1826), Berlin (Lichtenstein 1823; pers. obs.) or in the Natural History Museum, London (Boulenger 1887).

Anderson's journal and zoological manuscript also mentioned other reptiles, although no new names were provided for these. Cook (1784) ascribed to Anderson mention of several large blackish snakes at Adventure Bay (presumably copperheads, *Austrelaps superbus*, known from Bruny Island — Green & Rainbird 1993), although Anderson's journal (Beaglehole 1967) gave no indication of colour. [Note added in proof – One of the referees of this paper reported tiger snakes, *Notechis scutatus*, from Bruny Island. This species is also a possible contender for the large black snakes sighted by Anderson.] Anderson's manuscript descriptions listed two other lizards, in a separate appendix "Animalia genere dubio s[eu] imperfecte visa

continens". The first of these, also from Adventure Bay, and also mentioned in his journal ("a small sort, of a brown gilded colour above, and rusty below" — Cook 1784, Beaglehole 1967) was identified as similar to Linneaus' *Lacerta punctata*:

> 3. *Lacerta affinis punctata* /Corpus laeve subrotundrum. Cauda corpore longior teres. /Pedes pentadactyli unguiculati - Dorsum ex aureo-fuscum, /linea flava punctis nigris, interne terminatum - Lateres /nigri, linea albida infra. - Gula grisea, nigro punctata - Ab/domen ferrugineum -. /Habitat in terra Diemeni

This lizard is probably either *Niveoscincus metallicum* or *N. pretiosum*, both known from most nearby islands, although not formally reported yet from Bruny Island (Green & Rainbird 1993), neither species was formally named until almost a century later (O'Shaughnessy 1874).

The second lizard, from Otakoo Island, a locality I am unable to identify, is identified as similar to Linnaeus' *Lacerta gecko*:

> 5 *Lacerta affinis Gecko*? /L: Magnitudo dimidio Geckonis.? Corpus subluteum, /cauda mediocri, ore magna, auribus concavis, oculis gri/seis, iride lanceolata perpendiculare, pedibus unguicu/latis, digitisque subtus membranaeus.- /Habitat in insula Otakoo, taia.- Scandit arbores-.

It is possible that Otakoo Island is in Queen Charlotte's Sound, New Zealand, as Cook (1784) reported two to three sorts of lizards from this area.

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(accepted 17 July 2000)

THE DESERTIFICATION OF A BASS STRAIT ISLAND AND A PLAN FOR ITS RECOVERY: THE CASE OF EAST KANGAROO ISLAND, FURNEAUX GROUP

by Stephen Harris and Stephen Summers

(with two tables, four text-figures, three plates and two appendices)

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East Kangaroo Island is a low, mostly calcarenite-covered granitic island in the Furneaux Group which was observed in 1828 to have been fertile and well-wooded by *Allocasuarina verticillata*. Over 160 years of grazing and a succession of drought years have contributed to the decline of the native vegetation in biomass, ground cover and native species diversity. In the summer of 1999/2000, bare ground comprised 80% of the island, and the sparse vegetation mostly consisted of heavily browsed exotic grasses and herbs. The meagre flora of 91 taxa comprises 45% introduced species. The increased exposure from lack of vegetative cover has assisted the salt-wind-tolerant *Austrostipa stipoides* to spread inland, particularly from the west coast. An evaluation of the biomass puts the island within the range of that recorded for semi-arid deserts. Stock were removed in early 2000, and methods to restore the vegetation are proposed.

Key Words: flora, Furneaux Group, desertification, East Kangaroo Island, Nature Reserve, conservation, weeds, revegetation, ecological history, sheep-grazing impact, biomass, Cape Barren Goose management, muttonbird, Tasmania.

INTRODUCTION

East Kangaroo Island is a low-lying, granitic island 11 km southwest and windward of Whitemark on Flinders Island, situated at 147°54' longitude and 40°11' latitude. Comprising 144 ha, the island has had a long history of human activity, mainly as a grazing island for sheep but also as a venue for muttonbirding.

East Kangaroo Island was proclaimed as a Conservation Area in 1957 because of the value of the island's muttonbird (*Puffinus tenuirostris*) rookeries. The island was subsequently given the higher status of a Nature Reserve under the *National Parks and Wildlife Act* 1970 by virtue of Statutory Rule No.1984, 21. Prior to the proclamation of the Nature Reserve, 16 hectares of freehold land, as well as the then existing grazing lease, were purchased by the Government. The purchase and reservation of the island resulted from a recommendation by Pearse (1975). The island was then known to be one of the five most important Cape Barren Goose (*Cereopsis novaehollandiae*) breeding areas in the Furneaux Group. An agreement was reached to lease back the island for grazing after providing protection for the muttonbird rookeries. The value of the open pasture on the outer islands assists Cape Barren Goose breeding. The persistence of sheep-grazing under leasehold was considered beneficial to preserving the appropriate breeding habitat.

As early as February 1985, however, the Ranger-in-Charge of the Furneaux Group reported that "Kangaroo Island is the least desirable for a goose refuge. The problem is lack of adequate pasture" which he (Mooney 1985) attributed to overstocking in the previous 20 years, free-ranging stock and, since 1982 (a drought year), the poor seasonal conditions for pasture growth. Problems with the condition of the island continued to be raised by subsequent rangers (Arthur 1997, Summers 1998) culminating in the Government-requested destruction of the stock on the island in January 2000 and the commencement of planning for rehabilitation of the island.

The present study was prompted by the need to record the condition of the island at its worst, so as to measure the improvements which, it is hoped, will be achievable in revegetation. The island as a Nature Reserve has at present ceased being of value for its main purpose. There is a need for a strategy for revegetation and recovery which considers any values of the existing biota and environment. The behaviour of weeds and other species under a regime of managed vegetation recovery must also be anticipated.

METHODS

This study is based on several visits to the island, by ourselves and others. Dr I. Skira and Ms J. Balmer visited the island in April 1989 and recorded by photographs the damaged condition of the island.

(1) The history of grazing and occupation of the island was assembled through primary and secondary sources (e.g. Campbell 1828, Robinson in Plomley 1987, Sim & Gait 1992).

(2) A vegetation map was prepared from a 1986 black-and-white aerial photograph which was enlarged to 1:14 000. Boundaries were checked in the field and the patches assigned to a vegetation type. Comparisons were made with the vegetation on the latest colour aerial photography flown.

(3) A species list was compiled, and the voucher specimens of most species were lodged in the Tasmanian Herbarium (HO). A search of the National Herbarium of Victoria (MEL) was made for specimens from the island. Species occurring on the island were assessed for their nature conservation significance.

(4) The area of vegetation loss was mapped as two classes: severe and degraded. A "severe" classification was applied to the area with less than 300 kg/ha biomass and less than 20% vegetation cover, while "degraded" was applied to areas with less than 50% cover. Twelve plots of a nominal 30 m diameter were located in a stratified subjective manner

throughout the island and cover subjectively assessed within each. The aim was to evaluate cover across the island to verify air photo interpretation.

(5) A transect was located in two sections across the island so as to traverse the range of vegetation on the island. One-square-metre plots were located every 100 m along this transect (fig. 1) yielding 12 plots in which were recorded: soil type, depth, slope, exposure to wind, percentage cover of each species occurring in the plot, and other factors such as whether the plot was in a rookery or not. The percentage cover of the following categories was graphed: (i) bare ground/soil, (ii) bare rock, (iii) dead plant material/litter, (iv) moss, (v) thistle, (vi) mallow, (vii) exotic herbs (*Erodium cicutarium, Hypochoeris radicata, Acetosella vulgaris, Plantago coronopus* and *Euphorbia paralias*), (viii) *Chenopodium* spp, (ix) exotic grasses (*Trifolium* spp, *Agrostis* sp, *Catapodium rigidum*, other exotic Poaceae spp.), (x) native herbs and grasses (*Oxalis perennans, Dichondra repens, Geranium potentilloides, Spinifex sericeus*), and (xi) *Austrostipa stipoides.*

(6) The climatic history of the island as far back as 1943 was inferred from records at Whitemark airport. This coastal sea-level station is only 11 km to the northeast. Outer islands to the west of Flinders Island would be slightly drier, according to BIOCLIM modelling. The annual average rainfall was graphed and two missing data points for the years 1992 and 1993 were substituted by figures for Whitemark Post Office, a similar coastal sea-level station only 3 km south of the airport station.

(7) An estimate of biomass was achieved by collecting all plant material from seven stratified randomly located 1 m^2 quadrats and oven-drying overnight in an AGA oven. The plot size for biomass sampling accords with that proposed for some Central Australian vegetation types (Friedel 1977). Sample frequency is sufficient to give an indicative estimate. The resulting weights were averaged, where there were multiple samples from the same habitat, and extrapolated to give kilograms per hectare for *Austrostipa* tussock grassland, rookery area, skeletal soils on limestone and limestone pavements and the pasture land on granite. The results were then compared with estimates of biomass in arid rangelands in Central Australia (Friedel & Bastin 1988, Friedel *et al.* 1988).

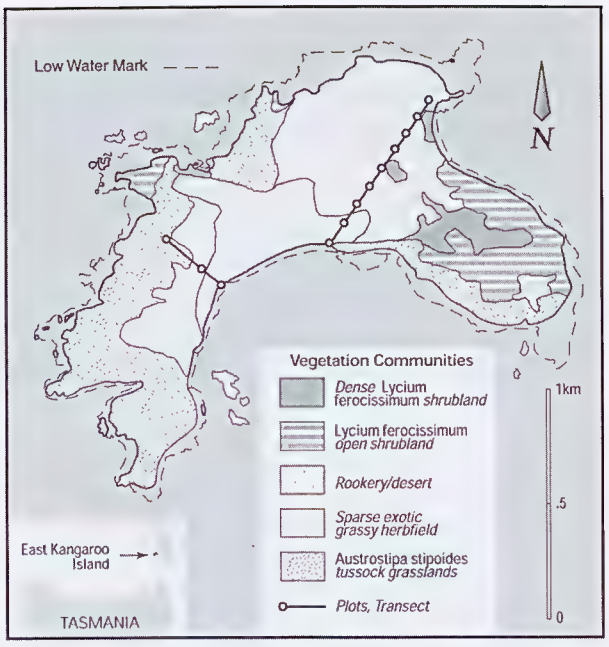

FIG. 1 — Map of the vegetation communities and the location of the transect and plots from which data for this study were drawn.

RESULTS

History of Grazing and Human Activity

The earliest record of East Kangaroo Island is Campbell's description of 1828:

> ... is the most fertile of the whole groupe, and abounds in wood of the sheoak species, the land is low, and at a distance appears like two separate islands, from being almost divided in the centre by a narrow sandy neck, wallaby abound in the thickets, and numbers of muttonbirds and green geese build their nests round the coast ...

By 1832, the island may have been largely cleared. Backhouse, the Quaker missionary, on his voyage among the islands in 1832 (Plomley 1987) stated that

> ...we passed Long Island, Badger Island, Chappell Island etc, and came safely to anchor under Green Island, the harbour for the settlement on Flinders... Many of the islands are low and grassy ...

In 1837, sheep from the Wybalenna settlement were being grazed on the island. Robinson (in Plomley 1987: 482) refers to a shepherd and assistant who were instructed to shear the sheep, weigh the wool and leave it in the men's hut. It seems reasonable to assume fairly continuous grazing until the present day, except that the island seems to have been unoccupied in 1861, at the time of the visit to the islands by surveyor Thomas, and from local knowledge it was stated to be inferior grazing, covered with barilla and lacking water (Sim & Gait 1992, Thomas 1861).

Canon Brownrigg visited the island in 1872 and reported (Murray-Smith 1979):

> In Kangaroo Island itself, there is nothing remarkable. Its length barely exceeds a mile and a-half, and its breadth about half a mile. Of the few dwarfish trees it ever possessed there remain scarcely half a dozen, and these are strictly preserved for the adornment they afford. Wood, for fuel, has to be boated in from Flinders. At the southern end of the island there is a mutton-bird rookery...

Interestingly, Brownrigg remarks at the same time on the condition of the nearby Green Island claiming that sheep and cattle appeared to thrive in spite of the sterile island, "utterly devoid of timber", no grass being seen except for a short period in spring.

> ... the entire surface is literally covered with sow thistles, and stinging nettles, with here and there barilla-bushes, and yellow everlastings.

Commercial exploitation of the muttonbird rookery played an important role in the economy of the island up until the 1920s . Non-commercial muttonbirding continued

until, in 1990, the rookery was closed due to degradation and declining harvest.

Baudinet was the occupier from the 1860s, but James Everett leased the island and at one stage had 300 sheep. In addition to Everett's stock, 60 sheep and 44 lambs are recorded as being grazed by Baudinet (Dr I. Skira, pers. comm.). In about 1876, the island passed over to the Harley family who then occupied it for two generations until other leaseholders took over pastoral activity on the island in the 1980s. A Flinders Island resident recollected (Griffiths 1927) that

> ... when the Harley family first went to Kangaroo Island it was a dense mass of scrub and it was some considerable time before they could introduce sheep...

We are uncertain about how to reconcile this statement with the observations of Brownrigg above, but, in any case, by 1884 they are recorded as running 810 sheep and 350 lambs on East Kangaroo Island (Tasm. Parl. Paper 89). In 1974, the Harley family stated that (Harley 1974):

> ... the island itself consist (*sic*) of natural pasture is never cultivated as there are considerable limestone rocks on the surface and many muttonbird rookeries, over which a tractor could not safely negotiate as many of these burrows are deep, at present we run between five and seven hundred sheep on it, and rely on the natural rainfall...

The island had a good grass cover around this time (pls 1, 2).

Traditional vegetation management on the island has included burning off the *Austrostipa stipoides* tussocks to allow sheep to graze on intertussock herbs.

The Vegetation

Five categories have been mapped (fig. 1). The only type of native vegetation remaining is *Austrostipa stipoides* tussock grassland, which occupies a zone which is exposed to westerly winds. The zone is wider than usual because winds have an unbroken sweep across the island and have extended the competitive advantage of *Austrostipa* across a wider area. There are two categories of shrubland dominated by *Lycium ferocissimum*: these may be distinguished according to density but the extensive area of *Lycium* open shrubland in the southeastern corner of the island has an *Austrostipa stipoides* lower stratum.

The Flora

The flora comprises 91 taxa from 36 genera. The best represented genera are Poaceae (n = 18 taxa) and Asteraceae (n = 10 taxa). No plants endemic to Tasmania were recorded. The only species listed on the schedules of the Tasmanian *Threatened Species Protection Act* 1995 is *Calystegia soldanella*, which is typically a strandline and foredune plant. It may be a vagrant on the island. *Threlkeldia diffusa* and *Apium insulare* are uncommon in Tasmania and are of biogeographic interest. These latter two species occur right on the coast, often in between granite boulders or on cobble beaches. Forty-one taxa are introduced in Tasmania, making 45% of the total island flora being composed of exotics.

PLATE 1

Pasture covers all soil in this photograph taken in 1977. The clumps are Austrostipa stipoides *and the foreground is strewn with limestone. Strzelecki Peaks are visible to the east. (Photo: I. Skira.)*

PLATE 2

*In 1977 when this photograph was taken, there was 100% grass cover where soil was present. Boxthorn (*Lycium ferocissimum*) is shown here encroaching over much of the land. (Photo: I. Skira.)*

Extent of Vegetation Loss

The vegetation loss is shown in figure 2. The most extensive loss is on the deepest soils, which are the alkaline sands coinciding with the rookery area. The next worst affected site types are the stony calcarenite areas, where soils are shallow and alkaline. Areas on shallow acid soils on granite have a sparse live vegetation cover but little bare ground — obscured largely by dead plant material. Where there are remaining tussocks of native grass, the survival of intertussock herbs appears best.

Species Composition and Cover in Major Habitat Types

Loss of cover is most marked in the rookery area. The successful survivors appear to be *Malva sylvestris*, *Chenopodium glaucum*, *Carduus tenuiflorus* and *Erodium cicutarium*. The rocky limestone areas have very poor cover and species diversity. Species in these sites include highly drought tolerant exotic and native herbs: *Geranium*

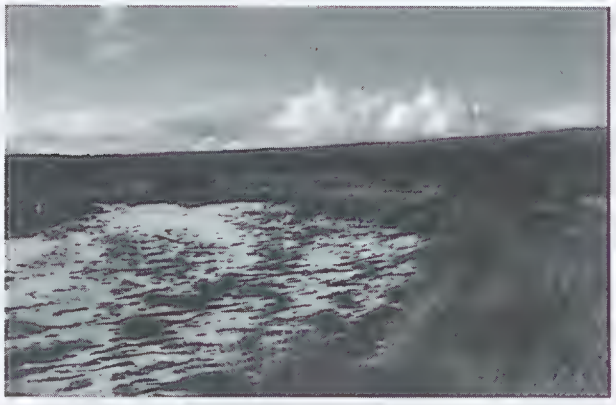

PLATE 3
The coastal belt of Austrostipa stipoides *grassland on the south coast of East Kangaroo Island is shown here in 1989. (Photo: I. Skira.)*

potentilloides, Plantago coronopus, Dichondra repens, Chenopodium glaucum, Erodium cicutarium and *Catapodium rigidum.* The *Poa* tussock areas on shallow acid soils over granite have a high cover of completely dessicated exotic grasses and herbs. Numerous tiny seeds, probably of *Trifolium,* were observed in some locations within this vegetation type. The *Poa poiformis* tussocks on the eastern side of the island have become sparse and heavily grazed. In contrast, the *Austrostipa stipoides* tussocks are dense in many places, and the grazing pressure is less because of the dense and prickly nature of the vegetation (pl. 3). The intertussock flora includes *Wahlenbergia* sp., *Euchiton involucratus, Pseudognaphalium luteo-album, Dichondra repens, Melilotus indica* and *Epilobium billardierianum.* On parts of the western ridge there are clints, grikes and solution holes in the limestone, which provide shaded and protected sites for some of the above species. The *Austrostipa stipoides* grassland occurring on the frontal sand dunes has a dense root system and the bases of the plants are surrounded by thick deposits of washed/blown up *Posidonia australis* seagrass and interspersed with *Euphorbia paralias.*

Climate

The rainfall records going back to the beginning of the Flinders Island airport station clearly show a prolonged period of below average rainfall in all the years since 1993, including the lowest recorded rainfall year ever in 1997(fig. 3A). The cumulative effect of this moisture deficit is best illustrated in figure 3B. No other period during the station's record has anywhere near such sustained low rainfall as in this recent period.

Biomass Estimates

Estimates are tabulated below. They range from a very low 4 kg per ha on the rookery to about 30 tonnes per hectare in the more dense *Austrostipa stipoides* grassland. The number of samples collected allow only an indicative estimate.

The biomass recorded for the limestone sands over the flatter central part of the island (rookery) is far lower than that recorded for any of the arid rangeland vegetation types reported from near Alice Springs by Friedel & Bastin (1988). The skeletal soils on limestone and limestone pavements at present support a biomass which is about half that recorded in an arid calcareous shrubby grassland near Alice Springs (Friedel & Bastin 1998). The *Austrostipa stipoides* grassland is 30 times the biomass of Mitchell grass plains, the highest yielding of the arid vegetation types recorded.

The alkaline sands and limestone soils are clearly able to support less vegetation on the island in drought conditions than the much more nutrient-poor acid coastal sands and granite soils.

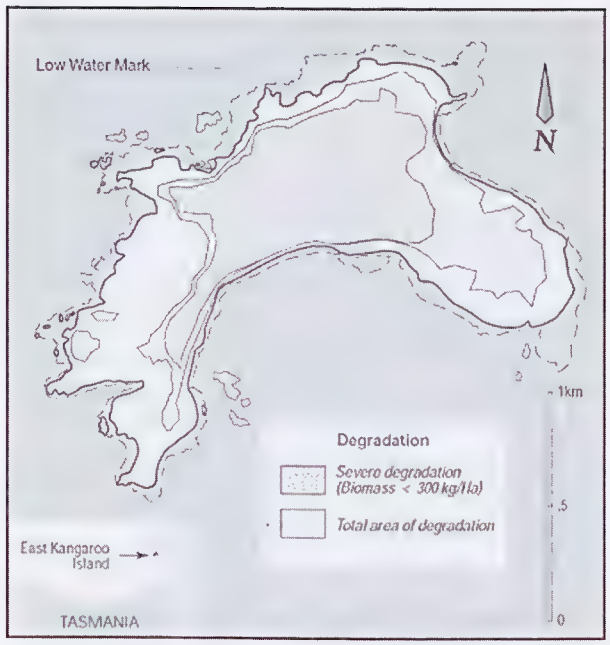

FIG. 2 — Map showing the extent of the degradation of vegetation cover on East Kangaroo Island as at January 2000.

TABLE 1
Biomass estimates for the four principle vegetation habitats on East Kangaroo Island

Habitat type	kg/ha	Number of samples
Grassland on granite: scattered *Poa poiformis* over dessicated exotics	1330	n=1
Skeletal soils on limestone and limestone pavements	300	X(n=3)
Rookery	4	n=1
Austrostipa stipoides dominated grassland	30 330	X(n=2)

DISCUSSION

The Processes to the Present

The island exhibits, in a most dramatic way, the results of processes which have operated on many of the outer islands (Harris & McKenny 1999). Clearance of original vegetation

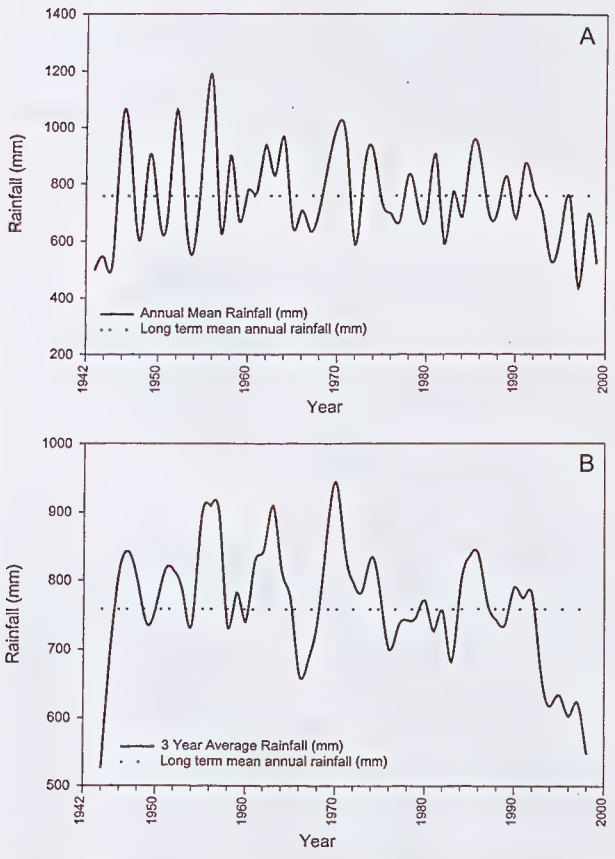

FIG. 3 — (A) Average annual rainfall at Flinders Island airport 1943–99, showing long-term mean annual rainfall; (B) The rolling three-year mean of annual average rainfall, indicating a cumulative moisture deficit in recent years.

by fire and axe was underway on many of the larger outer islands from the earliest years of the 19th century. East Kangaroo was still densely wooded in the 1820s. Clearing was probably inefficiently carried out, with the likely consequence that native shrubby vegetation persisted for some years. The 100 head of stock reported for the island in 1874 could have reflected this prevalence of rough pasture interspersed with low native scrub. The stocking rate varied between 500 and 700 sheep for much of the 1900s, and in January 2000 the number was around 500. Pasture grasses never needed to be sown, but Robin Walker (pers. comm.) claims that reseeding occurred by transporting to the island bundles of *Poa* which had been cut from roadsides on Flinders Island.

The stocking rate on the island has been consistent but, with declining rainfall since 1992 and a parallel decline in vegetable biomass production, there has been increasing pressure on the fast-dwindling pasture. The decline in pasture production below replacement rates occurs as rainfall continues below the recorded average. With a flock of sheep in a finite area putting relentless pressure on a decreasing resource, the impact becomes compounded until stock begin dying. Stock were deliberately destroyed before this point was reached.

There is no knowledge of what seed may be dormant in the soil, awaiting rain, or what proportion of any such seed might be exotics, or particularly undesirable ones. Widespread natural vegetation recovery cannot be expected because of the prolonged drought period, the loss of soil and the number of undesirable exotics which could take aggressive advantage of lack of normal vegetation cover. Some species which typically occur on the limestone soils of the Furneaux Group (Underewood 1998) are absent from the island, suggesting the possibility of local extinction due to land use activities.

Cape Barren gosling counts over the years reinforce the importance of the island as one of the main breeding islands in the Furneaux Group. Over a period from 1978–98 the island had an average gosling count of 427 (the third ranked island in the nine islands subject to census). Although the count fluctuates from season to season, a dramatic fall in numbers was recorded, from 403 in 1997 to 299 in 1998, and thence to 85 in 1999. Counts on other censused islands, by contrast were 10% up on the 1997 counts in 1998 and only 10% down on the long-term average (Hocking 1999). It is clear that the sudden decline in gosling numbers reflects the decrease in vegetation cover on East Kangaroo Island, which has resulted from a combination of low rainfall and grazing pressure. Once the vegetation has recovered, it is expected that the island will resume its importance as Cape Barren Goose breeding habitat.

Soil loss began to occur in the 1999/2000 summer. Large wind-borne soil plumes above East Kangaroo Island were observed from Flinders Island. The soil loss is from alkaline sands on the rookery. These sediments are of aeolian origin, so can become easily mobilised by the wind in the absence of vegetation. Bird bones are exposed on the rookery surface, indicating loss of soil. These are normally well below the surface in the burrows (Dr I. Skira, pers. comm.).

Reversing the Vegetation Decline

The island is distant from natural sources of plant propagules, apart from bird-dispersed Boxthorn (*Lycium ferocissimum)* (Peter 2000).

The management aims for the island will determine the revegetation plan. The principle aims are: (1) to protect and enhance the island as a Cape Barren Goose breeding island and (2) to protect the native plants of conservation significance. The other identified values of the island (Jennings 1976) are geological features of granodiorite emplacement, including well-defined foliation, oriented xenolithic rafts, dykes and cobweb fracture patterns with aligned feldspar phenocrysts. These are all hard rock features of the coast, which will be unaffected by any conceivable management regime on the island. There is no management plan for the island. Generic goals for Nature Reserve management are specified in the *National Parks and Reserved Land Regulations* 1999.

The recovery programme is advised to use the species shown in table 2, which can be readily propagated and have the best chance of survival.

Revegetation work should proceed over a winter period when humidity is higher and there is less likelihood of the soil being dry for extended periods. The island has no known vegetation conservation values inland of the immediate coast. As the island is potentially one of the best goose breeding islands and is already a Nature Reserve, planning for rehabilitation should allow for open grassy areas. An appropriate pasture seed mix (see appendix 2) is

TABLE 2
Native plant species recommended for revegetation work on East Kangaroo Island, their likelihood of being native to the island and the suggested source for propagation material

Species	Common name	Faithful to native flora	Source of propagules
Allocasuarina verticillata	Sheoak	B	airport
Rhagodia candolleana	Climbing saltbush	A	island
Tetragona implexicoma	Ice plant	A	island
Callitris rhomboidea	Oyster Bay pine	C	Badger Island
Leptospermum laevigatum	Coastal tea tree	C	Badger Island
Leucopogon lanceolatus	Shade beard heath	C	Badger Island
Alyxia buxifolia	Sea box	C	Furneaux Islands
Acacia sophorae	Coast wattle	C	Furneaux Islands
Poa poiformis	Coastal soft tussock	A	island

A = occurs on the island, B = previously recorded from the island, C = possibly occurred on the island.

proposed, to attain rapid cover, with expected soil-binding and drought-hardiness benefits. The grass seed should be partitioned into two lots with one lot being sown in April 2001. Sowing seed over two seasons will lessen the risk of establishment failure. Sheoak establishment should begin early, because this will be extensive and will be relied on for shelter belts as the trees attain maturity. Areas proposed for this treatment (fig. 4) would include a belt aligned north–south along the ridge at the western end of the island in addition to scattered copses. The sheoak should be cut as brushwood on Flinders Island and laid crisscross on the ground and on the *Austrostipa stipoides* tussocks. The drying branches will provide protection and some shade for the seedlings, which should emerge in large numbers from the cones. Other copses of sheoak would be treated in the same way — by laying cut branches heavily laden with ripe cones down on the ground and leaving them.

Copses of *Leptospermum laevigatum*, *Callitris rhomboidea* and *Leucopogon lanceolatus* would be situated through the central and eastern parts of the island from slash of material imported from Flinders Island and Badger Island. The slash would be laid down loosely over the ground in different orientations, then cone clusters of Oyster Bay pine collected from Badger Island would be dispersed over the top of these heaps.

The boxthorn must be kept in check and gradually eradicated. The island should be partitioned into operational units. Boxthorn eradication should be tried using Tordon™ granules, which can be applied at the rate of 35–45 n/m^2. The more isolated specimens of boxthorn would be treated first. An alternative treatment is by injection of Velpar® into the soil. Such treatment requires follow-on rain to mobilise the poison, death follows from 6–18 months. This chemical is highly mobile in the soil and in near coastal situations could leach out into littoral herbfields. The treated bushes should be left intact because physical removal may disturb the soil. The dead boxthorn cages are useful for assisting with the establishment of other plants, especially the climbing succulents *Tetragonia implexicoma* and *Rhagodia candolleana*. *Poa poiformis* clumps need to be transported to the island in large quantities and used for dividing and direct planting into the rookery soils. Vigorously growing tussocks, ideally having attained semi-mature growth after burning should be top-trimmed and planted in mid to late winter. *Tetragonia implexicoma* needs

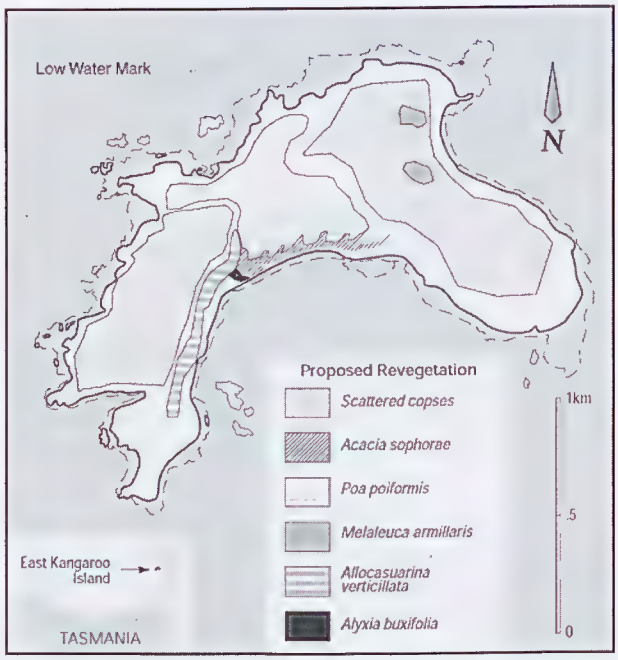

FIG. 4 — Map showing the proposed revegetation of East Kangaroo Island.

to be established throughout the rookery area at suitable intervals so that it will spread throughout the rookery and provide a good salt/drought tolerant cover.

The Department of Primary Industries, Water and Environment is committed to long-term land use for this island as a Nature Reserve and recognises that its primary management goal is for Cape Barren Goose breeding. This goal can be achieved, either with the development of tracts of pasture which could be maintained in conjunction with sheep-grazing, or by revegetating the island with native species and restoring the supposed pre-European habitat as faithfully as possible. The rehabilitation measures proposed in this paper do not compromise either course of action in the longer term. If the island is to retain some exotic pasture (and maintenance of grazed exotic pasture is likely to support a higher population of breeding geese) then it will coexist with shelter belts and copses of native trees and shrubs. Appropriate pasture grass seed is readily available and there is an urgent need to consolidate the soil. The

recommended mix (appendix 2) includes only species which are already established in the outer islands and are unlikely to threaten other values on the islands.

If stock are again permitted on the island, the allowable stocking rate will need to be reviewed. Some of the rookery area and areas regenerating to scrub would need to be fenced. The first priority is to rest the island for five years to allow an assessment of the vegetation recovery.

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APPENDIX 1

Higher Plant Census For East Kangaroo Island. Nomenclature follows Buchanan (1999). (I) following species name = introduced in Tasmania; (i) = new introduction of species formerly extinct on East Kangaroo Island. MEL = collections in the National Herbarium of Victoria, with collection numbers.

DICOTYLEDONAE

AIZOACEAE
- *Disphyma crassifolium*
- *Tetragonia implexicoma*

APIACEAE
- *Apium insulare*
- *A. prostratum*

ASTERACEAE
- *Actites megalocarpa*
- *Arctotheca calendula* (I)
- *Carduus tenuiflorus* (I)
- *Cotula coronopifolia*
- *Euchiton involucratus*
- *Hypochoeris radicata* (I)
- *Olearia axillaris*
- *Sonchus asper* (I)
- *Pseudognaphalium luteo-album*
- *Vellereophyton dealbatum* (I)

BRASSICACEAE
- *Cakile maritima* (I)

CAMPANULACEAE
- *Lobelia alata*
- *Wahlenbergia* sp.

CAPRIFOLIACEAE
- *Sambucus gaudichaudiana*

CASUARINACEAE
- *Allocasuarina verticillata* (i)

CARYOPHYLLACEAE
- *Cerastium glomeratum* (I)

Polycarpon tetraphyllum (I)
Sagina maritima (I)
CHENOPODIACEAE
Atriplex cinerea (I) (Whinray, MEL 530200)
Atriplex prostrata (I)
Chenopodium glaucum (I)
Chenopodium murale (I)
Chenopodium pumilio (I)
Rhagodia candolleana
Sarcocornia quinqueflora
Threlkeldia diffusa
CARYOPHYLLACEAE
Colobanthus apetalus (Whinray MEL 530190)
CONVOLVULACEAE
Calystegia soldanella
Dichondra repens
CRASSULACEAE
Crassula sieberiana ssp *tetramera*
EUPHORBIACEAE
Euphorbia paralias (I)
FABACEAE
Medicago lupilina (I)
Medicago polymorpha (I)
Melilotus indica (I)
Trifolium dubium (I)
Trifolium repens (I)

GENTIANACEAE
Sebaea albidiflora
GERANIACEAE
Erodium cicutarium (I)
Erodium moschatum (I)
Geranium molle (I)
Geranium potentilloides
Pelargonium australe
LAMIACEAE
Marrubium vulgare
MALVACEAE
Malva sylvestris (I)
MYOPORACEAE
Myoporum insulare
MYRTACEAE
Eucalyptus lehmannii (I)
ONOGRACEAE
Epilobium billardierianum
Epilobium sarmentaceum
OXALIDACEAE
Oxalis perennans
PLANTAGINACEAE
Plantago coronopus (I)
POLYGALACEAE
Comesperma volubile
POLYGONACEAE
Acetosella vulgaris (I)
Rumex brownii
PORTULACEAE
Calandrinia calyptrata
Montia australasica
ROSACEAE
Acaena novae-zelandiae
Acaena pallida
RUBIACEAE
Coprosma repens (I)
RUTACEAE
Correa alba
SOLANACEAE
Lycium ferocissimum (I)
Solanum nigrum (I)
URTICACEAE
Urtica incisa
Urtica urens (Whinray MEL 534002)

MONOCOTYLEDONAE
CYPERACEAE
Carex pumilio
Eleocharis acuta
Isolepis nodosa
Isolepis subtilissima
JUNCACEAE
Juncus bufonius
LILIACEAE
Bulbine semibarbata
POACEAE
Austrodanthonia racemosa
Austrofestuca littoralis
Austrostipa stipoides
Bromus diandrus (I)
Bromus hordeaceus (I)
Catapodium rigidum (I)
Dichelachne crinita
Holcus lanatus (I)
Hordeum murinum ssp *glaucum* (I)
Hordeum murinum ssp *murinum* (I)
Lagurus ovatus (I)
Lolium loliaceum (I)
Lolium rigidum (I)
Parapholis incurva (I)
Poa poiformis
Polypogon monspeliensis (I)
Spinifex sericeus
Vulpia bromoides (I)

APPENDIX 2

To re-establish pasture it is recommended that the following mix be sown in early May on all areas except the area mapped as *Austrostipa stipoides* grassland. Application rates are shown:

Lolium perenne cult. "Fitzroy"	3 kg/ha
L. perenne cult. "Vic"	4 kg/ha
Dactylis glomerata cult. "Tecapo"	3 kg/ha
Medicago sp. "Medic"	4 kg/ha
Trifolium subterraneum cult "Trickala"	4 kg/ha

The clover and medic should be treated by lime pellet innoculation to ensure appropriate *Rhizobium* is attached to the seed of each species. The seed should be broadcast by a hopper from a four-wheel-drive motorcycle, using community assistance if available. If logistically and economically feasible, in the first spring after sowing seed, some sheep, say 200, could be shipped over to graze the grass down to 75–100 mm to encourage tillering. The sheep should be moved off and the pasture rested before another grazing period the following year. Otherwise, reliance must be placed on Cape Barren Geese to do this. There can be no expectation that stock can be continuously on the island for at least five years, while basic revegetation work is carried out.

ROYAL SOCIETY OF TASMANIA
Papers and Proceedings

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PAPERS AND PROCEEDINGS OF THE ROYAL SOCIETY OF TASMANIA
VOLUME 134

Contents

page

Corrigenda — Volume 133, Part 1: Jackson, Ling; Volume 133, Part 2: Cover. iv

Refereed papers:

JACKSON, W.D. — Nutrient stocks in Tasmanian vegetation and approximate losses due to fire 1

HINGSTON, A.B. — Impacts of logging on autumn bird populations in the southern forests of Tasmania 19

PINDER, A.M. & ERSEUS, C. — New Phreodrilidae (Annelida: Clitellata) from Tasmanian estuaries 29

BRERETON, R.N. & TAYLOR, R.J. — Composition, seasonal occurrences and habitat use of bird assemblages in wet forests on the Central Plateau of Tasmania 35

WILLIAMS, K.J. & MARSDEN-SMEDLEY, J.B. — Reconnaissance survey of a glaucous eucalypt near Louisa Bay, southwestern Tasmania 45

JACKSON, J. — Threatened Trichoptera (caddisflies) from the Tasmanian Wilderness World Heritage Area 55

SUTER, P.J. — *Edmundsiops hickmani* sp. nov., *Offadens frater* (Tillyard) nov. comb. and description of the nymph of *Cloeon tasmaniae* Tillyard (Ephemeroptera: Baetidae) from Tasmania 63

GILMOUR, C.A., CROWDEN, R.K., VAILLANCOURT, R.E., & KOUTOULIS, A. — Genetic variation in the *Epacris tasmanica* complex (Epacridaceae) 75

SHEA, G.M. — The earliest taxonomic description and illustration of an Australian reptile: another historical first for bluetongue lizards (Squamata: Scincidae: *Tiliqua*) 79

HARRIS, S. & SUMMERS, S. — The desertification of a Bass Strait Island and a plan for its recovery: the case of East Kangaroo Island, Furneaux Group 83

Guide for authors 91

1504